Comparison of Lower Colorado River Irrigation Districts

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TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Five irrigation districts, including Imperial Irrigation District (IID), were reviewed using publicly available records and information relevant to the period 1988-1997. The other four districts are:

1. Colorado River Indian Reservation Irrigation District (CRIR).
2. Palo Verde Irrigation District (PVID).
3. Wellton-Mohawk Irrigation District (WMID).
4. Coachella Valley County Water District (CVWD).

Because more data were available for, IID, WMID and CVWD, these districts were reviewed in more detail, than PVID and CRIR. IID was addressed according to the water balance developed previously by NRCE, as presented in its 2002 report on IID water use. WMID was addressed on the basis of water records from Bureau of Reclamation (BOR) which include farm headgate delivery. CVWD was addressed by developing a water balance that includes available headgate delivery records from BOR and an estimate of groundwater contribution to irrigation water supply. PVID and CRIR were not addressed in detail because of the lack of headgate delivery records.

SUMMARY OF FINDINGS

Summary of District Water Use and Efficiency

Estimates of overall efficiency were determined for each of the irrigation districts for the 1988-1997 period of record according to records available. Specifically, calculation of conveyance & distribution efficiency (a single number reflecting the two components) and on-farm efficiency were possible for IID, WMID and CVWD only. This is because BOR does not include records of farm headgate deliveries for PVID and CRIR.

Overall Efficiency

The average ten year, overall efficiency for each district is 74.5% for IID, 62.2% for CRIR, 48.0% for PVID, 67.6% for WMID, and 67.3% for CVWD.

Conveyance & Distribution Efficiency

Conveyance & distribution efficiencies are 89.4 % for IID, 92.2 % for WMID, and 90.3% for CVWD.

On-Farm Efficiency

On-farm efficiencies are 83.4% for IID, 73.5% for WMID, and 74.5% for CVWD.

Overall efficiencies are the product of conveyance & distribution efficiency and on-farm efficiency. For example, the overall efficiency of CVWD is therefore 90.3% x 74.5% = 67.3%. Please note that other on-farm efficiency estimates for CVWD range from 57% to 70%. The Coachella Water Management Plan (2002) states an on-farm efficiency estimate of 70%. The difference is mostly attributable to the uncertainty of groundwater contribution to CVWD's irrigation water supply. Table 1 shows a comparison of various expressions of efficiencies for each district that were calculated. Tables of efficiency determinations for each district are presented later in this report according to sections which address each district separately. Efficiency estimates for IID come from the water balance presented in the 2002 NRCE report. Efficiency estimates for CRIR, PVID and WMID were determined from BOR records and a simple water balance reflecting Bureau data. Efficiency estimates for CVWD are based on a water balance; using estimated crop evapotranspiration, crop acreage, leaching requirement and groundwater that are not necessarily the same as those reflected by other investigators.

Summary of District Reference Evapotranspiration

Table 2 shows a summary of average daily reference crop evapotranspiration (ET_o) for each month for the districts addressed. ET_o was calculated using the Penman Monteith method applied to the climate data from stations representative of each irrigation district, however, the figures show that the use of climate data from CIMIS stations result in lower estimates of ET_o than for AZMET stations. The climate station at Palo Verde is a CIMIS Station and the station at Parker is an AZMET station. Comparison of ET_o estimates for PVID and CRIR show the difference most drastically. The two stations should produce similar results and therefore it would be expected that estimated ET_o should be close as well because of the proximity of these two metering stations. Furthermore, it is expected that the Net Irrigation Requirements (NIR) of a given crop should not vary greatly from district to district because of similar climatic conditions and cropping patterns shared by the districts. However, there is some discrepancy between California Irrigation Management Information System (CIMIS) ET_o and that reported by the Arizona Meteorological (AZMET).

Summary of District Soils

Table 3 shows a summary of the soils of irrigated lands for each district. It can be seen that the soils of CRIR, PVID, and WMID are predominantly alluvial soils of high permeability associated with the floodplains and terraces of the Colorado and Gila Rivers. The soils of CVWD consist mostly of alluvial material on fans and valley fill, providing a similar situation of high permeability. Although the CVWD soils are predominantly high in permeability, there are some examples of low permeability soils that exist in complexes with other soils. However, low permeability soils within CVWD comprise a small fraction of the total acreage of irrigated lands within CVWD. In contrast, the majority of the soils making up the IID service area are heavy soils that are predominantly low in permeability.

Summary of District Cropping Patterns and Leaching Requirements

Table 4 shows the cropping patterns and estimates of leaching requirements for each district. It can be seen that alfalfa comprises the majority of the acreage of all districts except for CVWD. PVID and CRIR have the lowest leaching requirements because the water diverted by these districts is lower in salinity than that of the other three districts. The leaching requirements for each district were estimated using Rhodes 1974 equation; however, it is believed that this method is inadequate for use on the heavy cracking clay soils found in IID. The Rhoades based leaching requirement for IID was 10.4 percent based on the crop mix presented in Table 4. The leaching fraction associated with IID was estimated by NRCE to be about 13.5 percent, based on the water balance developed in the March 2002, NRCE report on IID water use. The estimated leaching requirements of CVWD and WMID are 9.7 and 13.1 percent respectively. Citrus and grapes comprise about half of the irrigated acreage if ID# 1 in CVWD and nearly half of WMID's crops are alfalfa and lettuce. The estimated leaching requirements for CRIR and PVID are 8.6 and 7.6 percent, the smaller requirement largely a result of the better quality irrigation water available to CRIR and PVID above the Imperial Dam diversion point (which serves IID, CVWD, and WMID).

Table 1

Summary of Efficiency Estimates Lower Colorado River Irrigation Districts 1988 - 1997

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
A. Overall Efficiency											
IID (based on estimated NIR from water balance)	75.4%	74.6%	74.3%	75.9%	76.1%	73.9%	74.4%	72.5%	73.8%	74.0%	74.5%
CRIR	59.1%	61.9%	62.1%	61.1%	60.9%	61.6%	62.3%	64.0%	66.7%	62.2%	62.2%
PVID	49.4%	48.3%	50.1%	48.5%	43.6%	45.4%	47.8%	49.5%	51.8%	46.0%	48.0%
WMID	71.4%	70.1%	69.5%	67.0%	68.7%	56.4%	67.8%	63.6%	66.0%	75.2%	67.6%
CVWD (based on estimated NIR and Boyle acreage, incl. LR)	69.4%	61.5%	60.0%	64.8%	65.2%	73.1%	69.3%	70.2%	67.3%	71.6%	67.2%
B. Estimated On-Farm Efficiency											
IID (based on estimated NIR from water balance)	85.0%	83.3%	82.4%	84.9%	87.2%	82.8%	83.1%	81.3%	81.1%	82.5%	83.4%
CRIR	Farm Headgate Delivery Records not available from Bureau of Indian Affairs										
PVID	Farm Headgate Delivery Records not publically available.										
WMID	83.1%	82.1%	79.1%	72.9%	72.3%	58.7%	71.6%	66.3%	69.9%	79.4%	73.5%
CVWD (based on estimated NIR and Boyle acreage, incl. LR)	78.1%	69.1%	67.4%	72.1%	73.0%	80.3%	74.8%	76.2%	73.9%	79.8%	74.5%
C. Conveyance and Distribution Efficiency											
IID (based on estimated NIR from water balance)	88.7%	89.6%	90.2%	89.4%	87.3%	89.3%	89.5%	89.1%	91.0%	89.8%	89.4%
CRIR	Farm Headgate Delivery Records not available from Bureau of Indian Affairs										
PVID	Farm Headgate Delivery Records not publically available.										
WMID	85.9%	85.5%	87.9%	91.9%	95.0%	96.1%	94.7%	95.9%	94.4%	94.7%	92.2%
CVWD (based on estimated NIR and Boyle acreage, incl. LR)	88.9%	89.1%	89.0%	89.9%	89.4%	90.9%	92.7%	92.1%	91.1%	89.8%	90.3%

Table 2

Summary of Reference Evapotranspiration as Calculated Using Penman Monteith Method.

(Millimeters per Day)

10 Year Average Month	Calpatria	IID Seeley	Meloland	CRIR Parker	PVID Palo Verde	WMID Yuma	CVWD Thermal
January	2.2	2.3	2.2	2.6	2.1	3.2	2.2
February	3.0	3.3	3.0	3.7	3.0	3.9	3.2
March	4.4	4.8	4.4	5.5	4.6	5.3	4.8
April	6.0	6.4	6.3	8.0	6.1	6.8	7.0
May	8.0	8.4	7.9	9.8	7.2	8.3	8.3
June	9.1	9.4	8.6	10.8	8.3	9.5	9.4
July	9.0	8.7	8.6	10.1	8.5	9.6	9.0
August	8.4	7.8	8.1	8.8	7.6	9.0	8.3
September	7.1	6.4	6.5	7.6	6.1	7.9	6.9
October	5.1	4.8	4.8	5.8	4.3	6.0	4.9
November	3.1	3.1	2.9	3.8	2.8	4.2	3.0
December	2.0	2.0	1.9	2.6	1.9	3.0	2.1

Table 3
Summary of Predominantly Irrigated Soils within Five Districts

Imperial Irrigation District

Soil Complex	Permeability Inches/Hour	Description of Complex *Note: First soil series listed in complex is dominant*
a. Imperial	0.13 Low	Nearly level, moderately well drained silty clay in the lacustrine basin.
b. Imperial Holtville Glenbar	0.13 Low 0.9 Med 0.4 Low	Nearly level, moderately well drained and well drained clay, silty clay loam, and clay loam in the lacustrine basin.
c. Meloland Vint Indio	1.1 Med 2.3 Med 1.3 Med	Nearly level, well drained fine sand, loamy very fine sand, fine sandy loam, loam, and silt loam in the lacustrine basin.
d. Niland Imperial	5.1 High 0.13 Low	Nearly level, moderately well drained gravelly sand, fine sand, silty clay, and silty clay loam at the edges of the lacustrine basin.
e. Glenbar Imperial	0.4 Low 0.13 Low	Nearly level, well drained and moderately well drained silt loam, clay loam, silty clay loam, sand , fine sand, and silty clay dominantly in basins on West Mesa.

Colorado River Indian Reservation, Az., Portion

a. Gilman Glenbar Lagunita	1.30 Med 0.40 Low 13.0 High	Deep, well drained and somewhat excessively drained level to undulating, loamy and sandy soils; on flood plains.
b. Carrizo	>20 High	Deep, excessively drained, nearly level to gently sloping, very gravelly and sandy soils; on flood plains.
c. Superstition Rositas	4.0 High 13.0 High	Deep, somewhat excessively drained, nearly level to rolling, sandy soils; on on stream terraces and sand dunes.

Palo Verde Irrigation District, Ca., Portion

a. Carrizo	>20 High	Coarse textured soils in narrow washes from adjacent desert.
b. Imperial	0.13 Low	Relatively impervious soils to depths of 6 feet.
c. Holtville	0.9 Med	Relatively impervious soils over permeable subsoils.
b. Gila	Med to High	"Coarse to medium textured types of Gila series" "derived from mixed rock alluvium" Weir and Storie 1947. (*Permeability grouping based on textural description*)
e. Meloland	1.1 Med	Loose, permeable wind modified soils.
f. Rositas	13.0 High	Deep, excessively drained sands on old terraces and dunes.

Wellton-Mohawk Irrigation District

a. Indio Ripleły Lagunita	1.3 Med 8.1 High 11.8 High	Deep, nearly level to gently sloping, well drained and somewhat excessively drained, silty and sandy soils; on flood plains, low terraces, and alluvial fans and in drainageways.
b. Dateland Wellton	4.3 High 4.0 High	Deep, nearly level, well drained, loamy soils; on old alluvial fans and high terraces.
c. Ligurta Critobal Carrizo	1.1 Med 0.14 Low >20 High	Deep, nearly level, well drained and excessively drained, gravelly andn very gravely soils; on alluvial fans, low terraces, and flood plains.
d. Tremant Harqua Rositas	0.6 Med 0.4 Med 13.0 High	Deep, nearly level, well drained and somewhat excessively drained, gravelly and sandy soils; on terraces, alluvial fans, and sand dunes.

Coachella Valley Water District

a. Carsitas Myoma Carizo	13.0 High 13.0 High >20 High	Nearly level to moderately steep, somewhat excessively drained or excessively drained sands, fine sands, gravelly sands, cobbly sands and stony sands on alluvial fans and valley fill.
b. Myoma Indio Gilman	13.0 High 1.30 Med 1.30 Med	Nearly level to rolling, somewhat excessively drained to moderately well drained fine sands in dune areas and loamy fine sands, very fine sandy loams, fine sandy loams and silt loams on alluvial fans.
c. Gilman Coachella Indio	1.30 Med 4.0 High 1.30 Med	Nearly level to rolling, somewhat excessively drained to moderately well drained fine sands, fine sandy loams, silt loams, loamy fine sands, and very fine sandy loams on alluvial fans.
d. Salton Indio Gilman	0.13 Low 1.30 Med 1.30 Med	Nearly level, somewhat poorly drained to well drained silty clay loams, very fine sandy loams, fine sandy loams, and silt loams in lacustrine basins. *Note: Salton series soils comprise less than 2% of irrigated lands within ID #1.*

Table 4
Summary of Crops and Leaching Requirements

Imperial Irrigation District

Crops	Salt Tolerance	% Acreage
Alfalfa	MS	32.02%
Wheat (Durum)	T	12.96%
Sudan Grass	MT	11.61%
Sugar Beets	T	6.98%
Lettuce	MS	4.42%
Cantaloupes (1)	MS	3.00%
Bermuda (seed)	T	2.90%
Carrots	S	2.73%
Bermuda (hay)	T	2.52%
Onions	S	2.03%
Acreage Represented by Crop Patt.		81.17%
Weight Average Leaching Req.		**13.5%**

*Leaching Fraction based on NRCE water balance

Colorado River Indian Reservation, Az. Port.

Crops	Salt Tolerance	% Acreage
Alfalfa	MS	52.05%
Cotton Lint	T	31.19%
Wheat (assume Durum)	T	6.87%
Sudan Grass	MT	2.21%
Cantaloupes (1)	MS	1.54%
Bermuda (seed)	T	0.94%
Honeydew (1)	MS	0.74%
Onions	S	0.70%
Bermuda (hay)	T	0.57%
Oats	MT	0.57%
Acreage Represented by Crop Patt.		97.38%
Weight Average Leaching Req.		**7.6%**

*Based on Rhoades (1974)

Palo Verde Irrigation District

Crops	Salt Tolerance	% Acreage
Alfalfa	MS	49.35%
Cotton (short)	T	14.30%
Wheat (assume Durum)	T	7.40%
Sudan	MT	5.26%
Alfalfa Pasture	MS	4.15%
Lettuce	MS	3.66%
Cantaloupes (1)	MS	3.63%
Citrus	S	1.59%
Oats	MT	1.41%
Bermuda Grass	T	1.37%
Acreage Represented by Crop Patt.		92.12%
Weight Average Leaching Req.		**8.6%**

*Based on Rhoades (1974)

Wellton-Mohawk Irrigation District

Crops	Salt Tolerance	% Acreage
Alfalfa hay	MS	22.94%
Lettuce	MS	22.13%
Cotton Lint	T	18.14%
Wheat	MT	16.33%
other hay	NA	6.84%
Seed	NA	5.06%
Citrus	S	1.74%
Nuts	S	0.93%
Cauliflower (3)	MS	0.85%
Other Field (4)	NA	0.78%
Acreage Represented by Crop Patt.		95.74%
Weight Average Leaching Req.		**13.1%**

*Based on Rhoades (1974)

Coachella Valley Water District

Crops	Salt Tolerance	% Acreage
Citrus	S	22.32%
Grapes	MS	21.18%
Dates	T	8.85%
Corn	MS	7.21%
Lettuce	MS	4.65%
Other Veg (5)	NA	4.53%
Alfalfa Hay	MS	3.05%
Sudan Hay	MT	2.69%
Broccoli	MS	2.61%
Carrots	S	2.51%
Acreage Represented by Crop Patt.		79.62%
Weight Average Leaching Req.		**9.7%**

*Based on Rhoades (1974)

Notes:

(1) Melons estimated as Moderately Sensitive, Using 1300+3000/2 = 2150
(2) Oats estimated as Moderately Tolerant, Using, 3000+6000/2 = 4500
(3) Cauliflower estimated as Moderately Sensitive 2150.
(4) Other Field Crops assumed to be Moderately Sensitive at 2150.
(5) Other Veg. assumed to be Moderately Sensitive at 2150.

GENERAL DESCRIPTION OF DISTRICTS AND METHODS

Estimated quantities presented for IID come from NRCE's March 2002 report which developed a detailed water balance for the district. Unless otherwise indicated, most values for IID come from this report and are used to compare IID with other districts. Estimates of quantities for the remaining irrigation districts are based on sources such as the U.S. Bureau of Reclamation (BOR) and Natural Resources Conservation Service (NRCS, previously known as the Soil Conservation Service), information produced by the districts and conventional methods of assessment. Water balances for CRIR, PVID and WMID are based strictly on information available from BOR. The water balance for CVWD is somewhat more detailed because there was a need to address the lack of detailed irrigated acreage records and unanswered questions regarding groundwater contributions to the CVWD irrigation water supply (CVWD has historically maintained little or no public record of the amount of groundwater used for irrigation purposes within CVWD).

Records available from BOR are based on the Decree Method of Accounting, long used by BOR. BOR is developing a river accounting system called the Lower Colorado River Accounting System (LCRAS), which uses satellite imagery and interpretation to determine land use and irrigated acreage of crops. LCRAS was initiated in practice as a "Demonstration of Technology" in 1995; it is presently under development and has not replaced the Decree Method of river accounting. Presently available versions of LCRAS do not include CVWD, IID or WMID as they are off stream water users. In the future, irrigated acreage determinations along with diversion, return flow, and consumptive use, will likely be based on methods identified in LCRAS, if LCRAS or some form of LCRAS is eventually adopted for decree accounting purposes.

One of the primary physical differences between the districts reviewed is that CRIR, PVID and WMID lie within the lower portion of the greater Colorado River hydrological basin while IID and CVWD lie within the hydrologically isolated basin of the Salton Sea. This is significant because a large portion of the diverted water used by CRIR, PVID and to a lesser extent WMID, returns to the Colorado River. IID and CVWD, however produce no return flow to the Colorado River, as any returns from these districts make their way to the Salton Sea. Irrigation drainage water from IID and CVWD is however available to other users willing to make use of it. For example, the Metropolitan Water District has in recent years attempted to claim rights to use that water.

The elevation of irrigated lands among the five districts varies from less than 300 feet above sea level at CRIR to a low of approximately –230 feet below sea level at IID. CRIR lies almost directly below Parker Dam, has irrigated lands on both sides of the Colorado River, and is immediately upstream from PVID. Both districts are oriented along the Colorado River proper, while WMID is oriented along the Gila River, beginning at a point approximately five miles east of the confluence of the Gila and Colorado Rivers and continuing upstream for approximately 50 river miles. CVWD lies to the north of the Salton Sea while IID lies to the south; occupying the area between the Sea and the border with Mexico.

Climate

For the most part, the five irrigation districts have similar climates that are typical of the Lower Colorado River Basin. Frosts and maritime influence are uncommon. Naturally occurring vegetation on the mesas includes desert brush and grass species such as creosote bush and galleta grass. The Colorado River Valley vegetation consists of cottonwood, willow, and tamarisk. Mesquite is found in intermediate zones between the valley floor and the mesa. Precipitation normally occurs in short, high intensity thunderstorms. Total annual precipitation averages from 2.4 to 4.2 inches per year with IID receiving the least and CRIR and PVID receiving the most.

Daily data were compiled from seven climatic stations, for the period of record, for the purposes of computing reference crop evapotranspiration (ET_o) for the irrigated districts. This was accomplished using the Penman-Monteith method, which requires the following input values: maximum and minimum air temperatures, relative humidity, wind speed, and solar radiation. Climate stations within California are part of the California Irrigation Management Information System (CIMIS) and those in Arizona are part of the Arizona Meteorological Network (AZMET). The following is a list of the stations and associated irrigation districts:

1.	CIMIS #41 Calpatria, California	Imperial Irrigation District
2.	CIMIS #68 Seelely, California	Imperial Irrigation District
3.	CIMIS #87 Meloland, California	Imperial Irrigation District
4.	AZMET Parker, Arizona	Colorado River Indian Reservation
5.	CIMIS #72 Palo Verde, California	Palo Verde Irrigation District
6.	AZMET Yuma Valley, Arizona	Wellton-Mohawk Irrigation District
7.	CIMIS #50 Thermal, California	Coachella Valley Water District

Soils

Comparison of the soils within these irrigation districts is based largely on soil surveys performed by the Soil Conservation Service (now the NRCS). The taxonomic classification, physical and agricultural properties of the soils, and their aerial distribution were determined by the NRCS. More detailed soil data were available for IID and CVWD base on various district studies. The acreage of soils based on limited permeability was determined for the irrigated areas within IID and CVWD. For PVID, CRIR, and WMID, acreage by permeability was not determined and their reviews consist of summaries of their respective soil surveys.

Crops

IID's annual statement of crops and acreage is known as *Imperial Irrigation District Annual Inventory of Areas Receiving Water*. Similar reports from the other districts were used in this study, such as crop reports from each district or from cropping data reported by the districts to the BOR. These were used to form cropping patterns for the period 1988-1997 based on available data. The cropping patterns were developed for each district by separately listing all crops (by district) for each year such crops were grown throughout the period of record. An average ten-year acreage value was determined for each crop by averaging the acreage devoted to that crop throughout the period of record. These average crop acreage values were then ranked by acreage to determine the ten most prevalent crops for each district's period of record. The cropping patterns derived for IID and CVWD comprised about 80% of the crops grown by IID and CVWD. The cropping patterns associated with CRIR, PVID and WMID include about 90% of the crops grown by those districts. For this study, determinations of total cropped acreage for each district is regarded as equivalent to the total annual cropped acreage, including multiple cropping as reported.

Water Supply

All of the irrigation districts rely on gravity diversion from the Colorado River, though some employ lifting of water within the district service area. It is noted that CRIR pumps some water from the river and WMID pumps water at various points within their canal system. Since CVWD employs more drip and micro irrigation methods, much of their system is pressurized and in addition CVWD's water supply is significantly augmented with local groundwater, which is of a much different water quality. In contrast, IID relies exclusively on surface water imported from the Colorado River. There is no usable groundwater in the IID service area as a function of tight soils and inferior ground water quality.

The average annual Colorado River salinity and flow rate measurements at Lee's Ferry, Parker Dam, and Imperial Dam, have been compiled for purposes of comparing salinity of water available among the various districts. Table 5 summarizes the data for the period of record 1988-1997 and shows that the salinity content of the Colorado River water increases as the river flows downstream. On average, the CRIR and PVID divert better quality water compared to WMID, CVWD, and IID.

Table 5: Average Annual Electrical Conductivity (mmhos/cm) and Average Annual Flow (cfs) at Three Locations.

*Note: numbers in italics are estimates based on partial year data.

	Lee's Ferry 9380000		Below Parker Dam 9427520		Above Imperial Dam 9429490	
Year	EC	Flow	EC	Flow	EC	Flow
1988	817	10,811	947	10,718	1,072	9,533
1989	757	11,074	899	9,697	1,140	8,311
1990	861	10,914	949	9,661	1,168	8,287
1991	921	11,581	1,004	9,500	1,243	7,924
1992	921	11,025	1,043	8,290	1,223	7,129
1993	897	11,391	990	7,552	1,230	6,554
1994	797	11,095	1,099	9,557	1,280	8,169
1995	807	14,096	1,086	12,162	1,260	7,692
1996	732	15,235	1,047	12,260	1,270	8,354
1997	719	21,099	981	14,136	1,147	10,318
Ave.	748.09	11,665.55	913.18	9,412.09	1,093.91	7,479.18

The BOR is responsible for compiling records of diversion and return flow as part of the administration of the 1964 Arizona v. California decree. These records are published each year as the *Compilation of Records in Accordance with Article V of the Decree of the Supreme Court of the United States in Arizona v. California, Dated March 9th, 1964.* The term consumptive use in this context means diversions minus returns (Total Diversion - Total Return = Consumptive Use). Additionally, the BOR compiles some records of crop production and water use. These are called *U.S. Bureau of Reclamation Crop Production and Water Utilization Data.* Records of this type exist for IID, CVWD, and WMID; however, BOR has apparently not collected similar records for PVID or CRIR.

Irrigation and Drainage

With the exception of CVWD, the irrigation districts use primarily surface irrigation methods, though some sprinkler irrigation is used in all districts. CVWD has substantially more land devoted to permanent crops and uses drip and micro-sprinkler systems primarily with higher quality ground water. CRIR and PVID produce significant irrigation drainage flow that returns directly to the Colorado River, but CVWD and IID contribute no return flow to the Colorado River. The irrigation drainage water from IID and CVWD flows to the Salton Sea. WMID produces drainage water that discharges to the shallow groundwater aquifer associated with the District and in addition is removed via drainage canal that bypasses the Colorado River and discharges to Mexico. The reason for this bypass is the WMID drainage water is highly saline and bypass is necessary to meet Mexican Treaty water quality obligations.

District Water Use Assessments

Water use efficiency of IID was determined based on the results of the water balance developed by NRCE in the 2002 report. A determination of district water use efficiency for CRIR, PVID and WMID districts was estimated using a simple water balance method based on flow records from BOR, though headgate delivery records are unavailable for PVID and CRIR. Estimates of efficiency for CVWD are based on a more detailed balance that reflects best assumptions regarding irrigation practices and groundwater contributions to irrigation water supply. Efficiency estimates were made for overall, conveyance and distribution, and on-farm components for each irrigation district.

Overall efficiency is an expression of the net quantity of water used for the intended purpose compared to the gross quantity of water entering the overall system. Overall efficiency therefore includes conveyance/distribution and on-farm efficiencies. Conveyance/distribution efficiency is an expression of the gross quantity of water entering and leaving the conveyance/distribution portion of the system and is descriptive of the "plumbing of the system," including the canals and pipelines. On-farm efficiency applies to the water entering and leaving the farm unit and is therefore descriptive of the on-farm irrigation process itself.

BOR has complete records of total river diversion and return flows for each district and are available from the *Compilation of Records in Accordance with Article V., of the Decree of the Supreme Court of the United States in Arizona v. California.* These records are based largely on gaged flow records and in some situations unmeasured return flow estimates, and for the most part reflect the water balance of the river system. For some irrigation districts, the BOR possesses complete records of more detailed data which include a breakdown of water use by type. These records are called *Crop Production and Water Utilization Data* and include a statement of farm headgate delivery. It should be pointed out that these are annual statements and do not include monthly data. Such data are likely collected and kept by the irrigation districts themselves. CRIR and PVID do not report these records.

The estimated efficiency figures for CVID were developed using the amount of water estimated to be consumed by the crops grown within CVWD. This determination is based on the calculation of crop evapotranspiration and estimated total water consumed. Estimation of the quantities of water required by the crops are generally sound as accurate climatic data are available to allow for the calculation of reference evapotranspiration and the characterization of crop specific water use at various crop growth stages. Potential crop evapotranspiration represents the upper limit of water required by crops. The actual amount of water consumed by irrigated crops is however subject to cultivation practices.

Water Use Records

Water use records represent annual estimates of water supply, use and loss at various locations within a given district as recorded by the BOR. To the extent data were available for each district, the records used for this purpose are:

1. Cropped Acreage,
2. Total Diversion (from the Colorado River),
3. Return Flow (to the Colorado River),
4. Headgate Delivery, and
5. DCM&I (Domestic, Commercial, Municipal and Industrial).
6. Groundwater contributions to CVWD irrigation water supply were estimated as 15% of CVWD's surface water supply, as presented in the report: Coachella Valley Water Problem: Severe Groundwater Overdraft "Possible Strategies and Opportunities" (CVWD 1997).

Annual acreage is reported publicly by all the districts. These figures tend to represent peak acreage on a yearly basis. Items 2-3 above were available and are reported for each district within the USBR's document entitled *Compilation of Records in Accordance with Article V., of the Decree of the Supreme Court of the United States in Arizona v. California, Dated March 9th, 1964.* Items 4-5 appear in the BOR document entitled *Crop Production and Water Utilization Data* for CVWD, IID and WMID only. All records associated with CRIR are supposed to be compiled and kept by the U.S. Bureau of Indian Affairs, which has not kept records of water use within the Reservation project for the study period due to the lack of a Reservation hydrologist [1]. According to the BOR, PVID does not report quantities of acreage or water use to BOR[2].

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[1] Phone conversation with Conrad Kresge of BIA, 08/99.

[2] Phone conversation with Ms. Freddie Hood of BOR, 08/99.

Agricultural Water Requirement for CVWD

A more detailed water balance was necessary to estimate water use efficiencies associated with CVWD due to the lack of detailed records of irrigated acreage and the use of groundwater for supplementing the irrigation water supply. Additional components developed for this district water balance include:

1. Estimated Crop Evapotranspiration (ET_c),
2. Leaching Requirement,
3. Effective Precipitation, and
4. Adjusted Net Irrigation Requirement.

Crop Evapotranspiration

Annual estimates of crop evapotranspiration (ET_c) were determined for CVWD for each year within the study period. This was accomplished by multiplying the daily reference crop evapotranspiration (ET_o) by daily crop coefficients (K_c values), corresponding to each of the crops identified in the district's cropping pattern. The result is a set of daily evapotranspiration figures for each crop for the entire study period. These daily ET_c values were condensed into annual ET_c estimates for each year of the study period. K_c values and the growing season lengths were taken almost entirely from those presented by the Water Study Team (WST, 1998). WST generated a detailed set of crop coefficients and growing seasons for most of the crops grown by IID and are believed to be equally applicable to CVWD.

Because efficiency estimates for CVWD are based partly on crop evapotranspiration (ET_c), it was necessary to consider the effects of management and environmental conditions on crop water use. Specifically, estimated ET_c based on ET_o and K_c values represents the upper limit of crop requirements and do not address the less than ideal management and environmental conditions which actually exist in the field. These include, for example, soil and irrigation water salinity, low soil fertility, irrigation non-uniformity, pests and diseases that contribute to less than optimal yield. Research data on crop water use and related yields for alfalfa and corn indicate that potential yields and corresponding ET_c under ideal conditions may be 20 and 10 percent greater than actual field yields and corresponding ET_c for alfalfa and corn, respectively (Hillet al., 1983). In other words, ET_c of forage crops grown under field conditions may be 20 percent lower than the theoretically estimated ET_c. For the other crops, the field ET_c would need to drop 10 percent from theoretical estimates to reflect actual field ET_c. Because of this, adjustments were made to compensate for these differences. IID crop water requirements were treated in the same manner within the water balance presented in the 2002 NRCE report concerning IID water use.

Similarly, crop evapotranspiration was further adjusted to reflect an increase in the amount of water resulting from water evaporated during pre-irrigation of crops. It was assumed that 2.5 inches would be required for annual crops. For perennial crops, like alfalfa, the 2.5 inches was divided by 4 to reflect the annual amount required by a crop which received a pre-irrigation once in every 4 year planting cycle. Perennial crops like orchards received 2.5 inches per year. These adjustments and the estimated leaching requirements are combined to produce the Adjusted Field Requirement, which represents the amount of water expected to be consumed on-farm. Assessments of field related water uses for PVID and CRIR have limited value, since the lack of headgate delivery records for PVID and CRIR precludes the determination of on-farm and conveyance & distribution efficiency.

<u>Leaching Requirement</u>

Leaching requirements for IID were determined in the March 2002 NRCE report as part of the water balance for the district. In this case the leaching requirement determination reflects the fraction of irrigation water infiltrated given the circumstances of the leaching characteristics of heavy, cracking clay soils which dominate IID farms. The majority of the irrigated areas associated with the other four districts are comprised of light soils and therefore leaching requirements for those districts were estimated using Rhoades (1974) method (Equation 1), which is suitable for non-cracking, permeable soils, where:

$$LR = \frac{EC_{iw}}{(5EC_e - EC_{iw})} \qquad \text{(Equation 1)}$$

where:

LR = Leaching Requirement,

EC_{iw} = Electrical Conductivity of Irrigation Water,

and EC_e = Electrical Conductivity of Soil Extract.

Based on this approach, the leaching requirement is strictly a function of the electrical conductivity of irrigation water applied and that of the soil extract at saturation, which is set equal to the salt tolerance of a given crop. The result is indicative of the amount of water required to pass through the soil for maintenance of the desired root zone salinity. When determining the leaching requirement, the electrical conductivity of the soil water extract EC_e is replaced with the salt tolerance for a specific crop. The salt tolerance rating, developed by Maas (1990), was used to assign each crop a salt tolerance rating for purposes of estimating leaching requirement, based on "top ten crops" associated with each district. Estimates of each district's leaching requirement (other than IID) were determined and represent a weighted average acreage based on each district's cropping pattern.

The salinity tolerance of crops from Mass (1990) represents the salinity of root zone water at which yields will begin to decline. The qualitative terms Sensitive, Moderately Sensitive, Moderately Tolerant, and Tolerant define four classes of salt tolerance. The ranges of soil water salinity at which no yield reduction is caused are shown below (Mass 1984) where 1.0 dS/m = 1,000 uS/m = 1,000 umho/cm.

Relative Crop Salinity Tolerance	Soil Salinity (dS/cm)
Sensitive	0.0 to 1.3
Moderately Sensitive	1.3 to 3.0
Moderately Tolerant	3.0 to 6.0
Tolerant	6.0 to 10.0

For crops such as citrus and nuts, leaching requirements were reduced to reflect high frequency irrigated crops associated with drip and micro-sprinkler systems.

Adjusted Field Requirement

For CVWD the Unit Adjusted Field Requirement and Adjusted Field Requirement represent the gross amount of water consumed at the field level and are expressed in terms of the per-acre unit requirement and total acre-feet requirement, respectively.

Effective Precipitation and Adjusted Net Irrigation Requirement

Effective precipitation was determined for purposes of the water balance used for IID and CVWD. Effective precipitation and NIR determinations were not necessary for the other districts because in the case of WMID, BOR records are complete and allow for the determination of water use efficiency, on this basis. In the case of PVID and CRIR, no determination of effective precipitation and NIR were necessary because of the lack of headgate delivery records, which preclude identification of farm water use.

Effective precipitation is the amount of precipitation available to a crop and is considered effective if it contributes to the water requirements of the crop. There are a number of methods for determining the fraction of precipitation that becomes available to a crop or that portion which is considered effective. For purposes of this comparative study, the SCS method of estimating effective precipitation was used assuming the standard 3 inch depth of application. The SCS method of determining effective precipitation is presented in *Technical Release 21, Irrigation Water Requirements U.S. Department of Agriculture, SCS, revision 1970.* This method was also used for purposes of the IID water balance, in the NRCE 2002 report.

Net Irrigation Requirement (NIR) is the net amount of water necessary for the crop at the field level and is often expressed on a per-acre basis. NIR is calculated by subtracting effective precipitation from the estimated crop evapotranspiration. It is the amount of water required by the crop and does not include additional water necessary for leaching of salts or the amount of water necessary to overcome losses or inefficiencies due to application of irrigation water on the field. For purposes of this study, the Adjusted NIR represents Adjusted ET_c + Leaching Requirement – Effective Precipitation.

Estimation of System Efficiencies

Irrigation efficiency (IE) as defined by Charles Burt (1990) states that *(IE = Irrigation Water Beneficially Used / Irrigation Water Applied) x 100.* The two main components of this calculation are the beneficial use component, which includes the net irrigation requirement and the leaching requirement. Based on this definition, estimates of overall, conveyance/distribution, and on-farm efficiency have been determined for IID and CVWD. For each of the other three irrigation districts that have return flows to the Colorado River (other than IID and CVWD), Overall Efficiency was calculated as the ratio of (Total Diversion – Return Flow) / Total Diversion. This estimate represents an overall project efficiency, strictly on the basis of flow entering and leaving the district. Overall efficiency for CVWD is derived from the ratio of water beneficially used/ total diversion. This estimate is based on the adjusted net irrigation water requirement and reflects direct estimates of irrigated acreage, leaching fraction, and pre-irrigation. A summary of the quantities and the efficiency estimates are presented in each of the following sections corresponding to each irrigation district and then in summary at the end of this report.

IMPERIAL IRRIGATION DISTRICT - DESCRIPTION OF IRRIGATION DISTRICT

Approximately 97% of the water diverted by IID from the Lower Colorado River is used for irrigation. Use of groundwater for agriculture is negligible and surface irrigation is the dominant method used within the district.

Climate

The climate of Imperial Valley was characterized in the SCS Soil Survey of Imperial County California by the following properties:

Annual Precipitation	2.4 inches/year.
Mean Temperature	73 degrees F.
Growing Season (32 deg. 9/10 years)	300 days.

In order to provide a more detailed comparison of climate, actual data were compiled from three CIMIS climatic stations within the Imperial Valley. These stations are Calpatria (CIMIS #41), Seeley (CIMIS #68) and Meloland (CIMIS #87). These data were used for calculation of reference crop evapotranspiration (ETo), using the Penman-Monteith method, are summarized in Tables 6–8. It can be seen that there is little variation in annual average conditions, from station to station, for the period 1988-1997.

Table 6

IID Climate Station (Calpatria)

Average Monthly Figures

Cimis #41 Calpatria, California 1988-1997

Month	Air Temperature (F) Max	Min	% Relative Humidity Max	Min	Wind Speed m/s	Rs (MJ/day/m^2)	Rn (MJ/day/m^2)	ETo (mm/day)
Jan	68.9	38.4	86.8	35.9	1.8	11.9	3.8	2.2
Feb	74.0	42.2	85.6	34.1	1.9	15.6	6.3	3.0
Mar	79.7	45.8	83.8	29.1	2.1	20.7	9.6	4.4
Apr	86.1	51.0	80.5	23.8	2.3	25.6	13.0	6.0
May	93.1	57.7	72.0	19.2	2.8	28.4	14.9	8.0
Jun	101.5	63.9	64.1	16.8	2.6	29.5	15.6	9.1
Jul	105.6	72.6	67.4	22.5	2.6	27.6	15.4	9.0
Aug	105.4	75.5	69.8	26.0	2.5	25.6	14.3	8.4
Sep	101.4	69.2	71.0	23.1	2.3	22.1	11.0	7.1
Oct	91.4	57.3	72.8	21.1	2.0	17.6	7.1	5.1
Nov	77.7	44.8	79.7	26.1	1.9	13.0	4.1	3.1
Dec	68.1	37.2	84.9	34.1	1.7	10.6	3.0	2.0

Table 7

IID Climate Station (Seeley)

Average Monthly Figures

Cimis #68 Seeley, California 1988-1997

Month	Air Temperature (F) Max	Min	% Relative Humidity Max	Min	Wind Speed m/s	Rs (MJ/day/m^2)	Rn (MJ/day/m^2)	ETo (mm/day)
Jan	69.4	40.0	79.0	33.0	1.7	12.0	3.7	2.3
Feb	74.7	43.8	75.9	28.8	2.0	15.8	6.1	3.3
Mar	80.1	48.1	70.9	23.9	2.4	21.1	9.5	4.8
Apr	86.5	53.9	64.0	20.3	2.6	25.9	12.7	6.4
May	93.1	60.5	59.2	18.6	3.2	28.4	14.6	8.4
Jun	101.0	66.0	56.3	16.4	3.0	29.5	15.4	9.4
Jul	104.9	72.4	69.1	21.8	2.3	27.4	15.2	8.7
Aug	104.5	74.4	71.0	26.5	2.1	25.2	14.1	7.8
Sep	100.5	69.1	65.9	24.2	1.9	22.0	10.9	6.4
Oct	91.1	58.2	61.1	20.7	1.9	18.1	7.0	4.8
Nov	77.9	45.9	65.9	24.0	1.9	13.7	4.0	3.1
Dec	68.6	38.8	72.8	30.7	1.5	10.8	2.8	2.0

Table 8

IID Climate Station (Seeley)

Average Monthly Figures

Cimis #87 Meloland, California 1990-1997

Month	Air Temperature (F) Max	Min	% Relative Humidity Max	Min	Wind Speed m/s	Rs (MJ/day/m^2)	Rn (MJ/day/m^2)	ETo (mm/day)
Jan	69.2	40.9	77.8	35.6	1.7	11.9	3.8	2.2
Feb	74.1	44.8	75.7	34.2	1.9	15.6	6.2	3.0
Mar	79.2	48.5	74.4	29.7	2.3	21.0	9.8	4.4
Apr	86.6	53.9	69.3	24.5	2.6	26.3	13.3	6.3
May	93.4	60.0	64.8	22.8	2.9	28.8	15.3	7.9
Jun	101.6	65.4	60.2	20.8	2.5	29.5	15.9	8.6
Jul	105.9	73.1	65.2	23.6	2.4	27.4	15.4	8.6
Aug	106.2	76.6	66.7	27.2	2.3	25.6	14.4	8.1
Sep	102.0	71.2	68.1	26.5	2.0	22.0	11.3	6.5
Oct	91.6	59.1	66.7	23.8	1.9	18.1	7.4	4.8
Nov	77.1	46.9	74.9	29.8	1.9	13.5	4.4	2.9
Dec	67.5	39.6	77.0	35.0	1.6	10.5	3.0	1.9

Soils

The majority of irrigated lands within IID correspond to what was once the Salton Sea lakebed floor and is now the area south of the Salton Sea. These lands are comprised of soils that are primarily lacustrine in origin (lakebed soils), which explains the properties of the soils and irrigation management required within this area. Lacustrine soils are formed from the deposition of very fine sediments which settled out from suspension, forming the layers of mud on the bottom of the old lakebed. This is an important distinction between IID soils and those of other districts. Most of the soils of the other districts were formed from alluvial (river) and eolian (wind) induced processes that create coarser and therefore more permeable soils.

According to the SCS Soil Survey of Imperial County California, the predominant soils associated with the majority of the irrigation project are within the extent of the old lakebed. The basin is very flat, with the long axis of Imperial Valley sloping downward to the north, toward the Salton Sea, at about 0.1 percent and slopes about 0.3 percent from the east and west in towards the middle. Because this old lakebed is so flat, IID soils were formed primarily by the deposition of very fine sedimentary materials. The resulting soils are very fine grained and dominated by clay, but can include bands, streaks or layers of courser grained materials that were deposited locally along the stream courses of flood waters entering the basin.

Within IID, these courser materials have often been somewhat dispersed over localized areas by further alluvial and wind related processes subsequent to the formation of the original lakebed. It is however the abundance of lacustrine clay soils, within IID, that create conditions of low water permeability and while some soils and are characterized as well drained to poorly drained soils, the prevailing overall condition is one greatly limited permeability. The SCS states that in addition to the natural soil formative processes, "the natural drainage of these soils has been altered by the seepage of water from irrigation canals and by extensive irrigation." Such seepage has created high water tables in some areas that further reduce soil drainage. Within IID this shallow groundwater contains high levels of dissolved salts. Additionally, researchers, such as Grismer and Bali (1996 and 1998), have stated that many fields within IID are impacted by high water tables due to inadequacy of subsurface drain systems installed in heavy clay soils with high water tables.

Soils have been mapped according the identification of soils by the taxonomic classification called a "series." The soil map therefore represents the study area divided into soil mapping units that consist of areas exhibiting common characteristics. These units are named by the dominant series or the combination of series present. Among the soils encountered within these five irrigation districts, combinations of specific soil series are referred to as complexes. Complexes are combinations of soils that exist in intricately mixed patterns that preclude mapping them separately. Two separate categories of soils are described for IID. They are the Valley-Basin Soils and the Mesa Soils Adjacent to the Lakebed.

Valley-Basin Soils

The soils corresponding to most of the irrigated lands of IID are considered valley-basin soils and are broadly summarized in Table 7 according to the dominant characteristics of the surface layer.

Table 9: Description of Soil Series and Complexes of Soil Series Found within the Lacustrine Basin of Imperial Valley.

a. Imperial	Nearly level, moderately well drained silty clay in the lacustrine basin
b. Imperial-Holtville-Glenbar	Nearly level, moderately well drained and well drained clay, silty clay loam, and clay loam in the lacustrine basin
c. Meloland-Vint-Indio	Nearly level, well drained fine sand, loamy very fine sand, fine sandy loam, very fine sandy loam, loam, and silt loam in the lacustrine basin
d. Niland-Imperial	Nearly level, moderately well drained gravelly sand, fine sand, silty clay, and silty clay loam at the edges of the lacustrine basin.
e. Glenbar-Imperial	Nearly level, well drained and moderately well drained silt loam, clay loam, silty clay loam, sand, fine sand, and silty clay dominantly in basins on West Mesa.
f. Fluvaquents	Nearly level, poorly drained soils of undifferentiated texture in the lacustrine basin.

Mesa Soils Adjacent to the Lakebed

The soils of the mesa areas adjacent to the Imperial Valley comprise very little of the irrigated land within IID and are characterized primarily as well drained and somewhat excessively drained soils dominantly on east and west mesas adjacent to the lacustrine basin. The general soil mapping units of these areas are described in Table 10.

Table 10: Descriptions of Soil Series and Complexes of Soil Series Comprising the East and West Mesas Adjacent to the Lacustrine Basin of Imperial Valley.

a. Rositas	Nearly level to moderately steep, somewhat excessively drained sand, fine sand, and silt loam in alluvial basins and on fans and sand hills
b. Rositas-Superstition	Nearly level, somewhat excessively drained loamy fine sand or fine sand on alluvial terraces and fans.
c.Antho-Superstition- Rositas	Nearly level, well-drained and somewhat excessively drained fine sand and loamy fine sand in alluvial basins and on alluvial fans and terraces.
d. Holtville-Antho	Nearly level, moderately well drained gravelly sand, fine sand, silty clay, and silty clay loam at the edges of the lacustrine basin.
e. Glenbar-Imperial	Nearly level, well drained loamy fine sand, loam, silty clay loam, and silty clay on alluvial terraces.

Dominant Soil Series and Permeability of Irrigated Lands

Each soil series has its own distinguishable characteristics which define it physically and taxonomically and is distinct because of its chemical, physical and engineering properties. Permeability is a particularly important property in irrigation design and practice. The acreage of soils by mapping unit and the permeability of the limiting soil strata within each mapping unit have been estimated. The soils corresponding to the irrigated area within IID are summarized in Table 11.

Permeability, like other soil properties, often varies with the depth of the soil profile. Because of this, each property associated with a given soil mapping unit has a range of values which vary with depth. The value of limiting permeability shown in Table 12 is indicative of the degree to which water is limited when passing through the root zone of the crop. The acreage value in the table corresponds to the total acreage attributed to the soil mapping unit. Some soils found to occur within the area addressed are not considered arable and have not been characterized by permeability. The soils listed in Table 11 have been characterized by permeability group in Table 9. The permeability group is a class of soils according to the breakdown preceding Table 9.

Table 11. **IID Soils within Irrigated Boundary Sorted by Permeability of Limiting Layer in the Top Four Feet.**

Map Unit	Dominate Soil	Minor_Description	Acreage	Permeability Range (Low and High)		Limiting Permeability	Group Acreage	Group Percentage
109	Holtville	Silty Clay	2,589	0.06	6.00	0.06		
110	Holtville	Sillty Clay, wet	72,966	0.06	6.00	0.06	Low Permeability	
111	Holtville	Imperial Silty Clay Loams	3	0.06	2.00	0.06		
112	Imperial	Silty Clay	317	0.06	0.20	0.06		
113	Imperial	Silty Clay, Saline	2,500	0.06	0.20	0.06		
114	Imperial	Silty Clay, Wet	119,682	0.06	0.20	0.06		
115	Imperial	Glenbar Silty Clay Loams, wet, 0 to 2 percent slope	150,924	0.06	0.20	0.06		
116	Imperial	Glenbar Silty Clay Loams, 2 to 5 percent slope	1,375	0.06	0.20	0.06		
121	Meloland	Fine Sand	1,253	0.06	6.00	0.06		
122	Meloland	Very fine Sandy Loam, Wet	98,810	0.06	6.00	0.06		
123	Meloland	and Holtville Loams, wet	13,047	0.06	2.00	0.06		
124	Niland	Gravelly Sand	1,364	0.06	20.00	0.06		
125	Niland	Gravelly Sand, wet	6,543	0.06	20.00	0.06		
126	Niland	Fine Sand	459	0.06	20.00	0.06		
128	Niland	Imperial Complex, Wet	3,118	0.06	20.00	0.06		
144	Vint	Indio Very Fine Sandy Loams, Wet	15,369	0.06	6.00	0.06	490,320	86.9%
106	Glenbar	Clay Loam, wet	3,798	0.20	0.60	0.20		
107	Glenbar	Complex	969	0.20	2.00	0.20	Medium Permeability	
117	Indio	Loam	1,208	0.60	2.00	0.60		
118	Indio	Loam, wet	13,837	0.60	2.00	0.60		
119	Indio	Vint complex	6,435	0.60	2.00	0.60	26,247	4.7%
101	Antho	Supperstition Complex	31	2.00	6.00	2.00		
103	Carstias	Gravely Sand, 0 to 5 percent slope	237	6.00	20.00	6.00	High Permeability	
130	Rositas	Sand, 0 to 2 Percent Slope	775	6.00	20.00	6.00		
132	Rositas	Fine Sand, 0 to 2 Percent Slope	2,927	6.00	20.00	6.00		
133	Rositas	Fine Sand, 2 to 9 Percent Slope	19	6.00	20.00	6.00		
135	Rositas	Fine Sand, Wet, 0 to 2 Percent Slope	11,797	6.00	20.00	6.00		
136	Rositas	Loamy Fine Sand 0 to 2 Percent Slope	29	6.00	20.00	6.00		
137	Rositas	Silt Loam, 0 to 2 Percent Slope	8	6.00	20.00	6.00		
142	Vint	Loamy Very Fine Sand, Wet	31,790	2.00	6.00	2.00		
143	Vint	Fine Sandy Loam	3	2.00	6.00	2.00	47,616	8.4%
		Total	564,182				564,182	100%

Permeability	Permeability Range
Class	Inches/hour
Low	< 0.06
Medium	0.06-2.6
High	> 2.0

Table 12: Soils Permeability Grouping

Permeability Group	Acres	Percent Represented
High	47,616	8.4%
Medium	26,247	4.7%
Low	490,320	86.9%
Total	563,183	100.00%

The acreage figure in Table 12 is indicative of irrigable soils within the boundary of the greater IID irrigated land area but includes lands which are not irrigated.

The irrigated soils of Imperial Valley are primarily heavy soils of low permeability and intake rate. According to Bower (1989), "The soils of the IID consist of highly stratified, predominately clay and silt Colorado River deposit." Kaddah and Rhoades (1976), stated that "The soils of the valley [IID] have been deposited under lacustrine, semilacustrine, and deltaiec conditions within the valley and alluvial fan formations at the outer margins of the valley. They are highly stratified Entisols, and are divided into eight soil series according to the texture of the main soil section (25-100 cm depth). Soils having control sections of (i) clay and silty clay –Imperial soil series; (ii) silty clay loams, clay loams and sandy clay loams-Glenbar series; (iii) silt loams, loams, and very fine sandy loams-Indio series; (iv) fine sandy loams and loamy fine sands-Antho series; and fine sands-Rositas series. Three soil series contain two major strata of contrasting textures. Soils with fine textures such as silty clay overlying loamy textures, such as sandy and silt loam, fall into the Holtville series. Soils with an inverse stratification of coarse loamy over fine textures belong to the Meloland series. Local overwash of sand or gravelly sand underlain by clay textures is called the Niland series. The Imperial series belong to the Typic Torrifluvent Subgroup, the Rositas belong to the Typic Torripsamment Subgroup, and the rest of the series belong to the Typic Torrifluvent Subgroup. The acreage percentages of the various series in the irrigated land of Imperial Valley are estimated as 44% Imperial; 15% Glenbar; 15% Holtville; 8% Meloland; 8% Antho; 6% Indio; 2% Niland; and 2% Rositas".

The predominant soil type of IID is the Imperial Series comprising approximately one half of the soils in IID. It is of low permeability, often less than 0.10 inches per hour or 0.20 ft/day. In comparing IID soils with those of CVWD, Bower (1989) stated that "except for a few percent of clay loam soils near the Salton Sea, all CVWD soils are sandy loams or loamy sands having infiltration rates in excess of 1 ft/day, the impediment to drainage of the clay and silt lenses having been eliminated by a tillage operation called 'slip-plowing'. While it is evident that the infiltration rates of essentially all CVWD soils are sufficient to permit a reasonably high leaching requirement, this is not the case for most IID soils due to the predominance of fine textured soils comprised of high shrink-swell clay". (Bower, 1989).

Crops and Leaching Requirements

The SCS *Soil Survey for Imperial Valley* stated that over 20 different kinds of crops were grown in the valley in 1975. While this certainly accounts for the majority of crops grown, over 110 different crops are listed in Imperial Irrigation District's *Inventory of Areas Receiving Water* and this does not include seasonal variations or crops grown for seed. The top ten crops comprise about 80% of the total crops grown for the average year for the period 1988 to 1997. For this period of record, the maximum, minimum, and average total irrigated acreage of IID was 564,873 (1997), 497,659 (1988) and 536,136 acres, respectively, and includes multiple cropping. Table 13 shows the top ten crops grown by acreage, crop type, and the salt tolerance rating.

Of all crops grown in IID during this period, 2.8% were permanent, 21.1% were garden, and 76.1% were field crops. The total category percentages with regard to salt tolerance of crops are as follows: 2.5% - no category (according to Maas), 6% Sensitive, 12.3%

Moderately Tolerant, and 29.6% Tolerant, 49% Moderately Sensitive. On this basis and using the Rhoades equation for determining leaching requirement, NRCE preliminarily estimated the standard leaching requirement to be 10.4 percent. This method is not however appropriate for IID because it does not address leaching conditions associated with cracking clay soils.

Table 13: Top Ten Crops by Acreage, Imperial Irrigation District, 1988-1997.

Crop	Crop Type	Salt Tolerance	Average Acreage	% of Acres	Running Sum %	Count
Alfalfa, Flat	Field	MS	171,690	32.02	32.02	1
Wheat	Field	T	69,491	12.96	44.99	2
Sudan Grass	Field	MT	62,222	11.61	56.59	3
Sugar Beets	Field	T	37,428	6.98	63.57	4
Lettuce	Garden	MS	23,684	4.42	67.99	5
Cantaloupes (Spring)	Garden	MS	16,060	3.00	70.98	6
Bermuda Grass (Seed)	Field	T	15,523	2.90	73.88	7
Carrots	Garden	S	14,649	2.73	76.61	8
Bermuda Grass	Field	MS	13,535	2.52	79.14	9
Onions	Garden	S	10,876	2.03	81.17	10

Prior to the time period considered above, Bower (1989) summarized the crops grown in IID according to salt tolerance, with 11% sensitive, 41% moderately tolerant, 48% highly tolerant. He calculated the leaching requirement based on the concentration of dissolved solids from the soil water extract, these correspond to 3,250, 5,850 and 9,200 parts per million respectively. Using 850 ppm total dissolved solids (TDS) for the irrigation water produced an estimated leaching requirement of 11.9%. Taking into account the heavy clay cracking soils of IID, NRCE estimated a leaching fraction of about 13.5 percent using the water balance presented in the 2002 NRCE report.

Water Supply

The Imperial Irrigation District receives its water supply entirely from the Colorado River diversion at Imperial Dam by way of the All American Canal. The quality of irrigation water used by IID is similar to that of WMID as well as the surface water portion of CVWD's water supply. The Colorado River is diverted to these three districts at Imperial Dam. The average specific conductance and the corresponding flow at a location just upstream from Imperial Dam is 1,209 uS/cm and 8,034 cfs, based on the period of record 1990-1998. The corresponding average specific conductance and average flow rate of the Colorado River at Lee's Ferry is 814 uS/cm and 13,301 respectively. Specific conductance of water is an expression of the conductivity of water as determined by a standardized procedure, whereby the resistance or voltage drop across an emersed anode and cathode of fixed distance, determined. It is expressed in micro-Siemans per centimeter (uS/cm) or equivalent unit of conductance. It is used as a surrogate measurement of total dissolved salts within the water, where the ratio of proportionality is dependant on the actual constituent ions and cations. One thousand uS/cm is about 640 ppm TDS.

Diversion

IID diverts water from the Imperial Dam. The amount of water described as the net supply for IID is stated for a location just upstream of the East Highline Canal. For the period 1988-1997, IID's average net supply was 2,799,000 acre-feet of water.

Conveyance and Distribution

Water diverted from Imperial Dam to IID and CVWD is transported by means of The All American Canal. At a point near the eastern edge of IID, some of the flows of the All American Canal are diverted into the Coachella Canal, serving CVWD. The majority of flow continues onward to the East Highline Canal and other subordinate conveyance canals. The average annual total of the farm headgate deliveries for the period 1988-1997 was 2,503,300. IID's conveyance and distribution efficiency was about 89% based on-farm headgate delivery divided by net supply.

Irrigation and Drainage

Although surface/flood irrigation is predominant in Imperial Valley, sprinkler irrigation is sometimes used for leaching and germination of crops. Surface irrigation is well suited to IID for a variety of reasons, for example: level lakebed topography, the low intake rates of the soils, the consistency of IID's water supply, the nature and design of the IID water delivery and management system, the salinity of the water, the large field areas irrigated and the types of crops grown.

An extensive network of open and subsurface drains, about 1,460 and 33,627 miles respectively, drains the lands of IID. According to Kaddah (1976), open drains provide outlets for surface and subsurface drainage water. Except for some drains in the north that discharge directly into the Salton Sea, the open drains discharge into the Alamo and New Rivers, which in turn discharge by gravity-flow into the Salton Sea. Open drain construction began in about 1921 to alleviate the water logging and salinity problems that had developed in the valley. The system was only partially successful and the need for more field subsurface drains became urgent because of salt accumulations in the soils. Farmers began to install tile drains on their land as early as 1928. Now about 156,000 [1976] ha or (385,000 acres) or about 88% of the irrigated area in the valley has tile or plastic tube subsurface drains installed 1.5-1.8 m (5-6 feet) deep at spacings of 15-75 m (50-250 feet). This drainage system represents a huge investment toward the maintenance of sustained long-term agriculture in the Imperial Valley.

IID WATER USE ASSESSMENT

According to Boyle (1990), fields within IID tend to be deficit irrigated. This has impacts on irrigation efficiency in that the historical crop irrigation water use has been less than the potential and optimum crop irrigation water requirement. This results from the following conditions:

- Soils have low intake and drainage rates that inhibit leaching.
- In cases where tailwater is deemed excessive, IID imposes an assessment of three times the cost of water for tailwater that can result in under irrigated conditions.
- Water is available only in twelve-hour block deliveries.
- Over irrigation or ponding of water on some crops causes scalding and can result in irrigator judgment favoring water control timing to minimize ponding.
- Variations in crop density and or vigor.
- Variations in scheduling of farm operations.

Elimination of deficit irrigation requires more water to be applied, which would result in greater tailwater and drainage flow and lower irrigation efficiency, but would result in higher yields and better leaching results. Table 14 summarizes water use and efficiency for IID.

Table 14 represents a determination of water use based of results from the water balance analysis, presented in the March 2002 report by NRCE. In the case of IID, no return flow is reported because no portion of the net supply, as measured near the East Highline Canal, returns to the Colorado River. For IID, overall efficiency is estimated on the basis of NRCE's 2002 water balance and is 74.5 percent. The estimated conveyance/distribution and on-farm efficiencies are 89.4 and 83.4 percent based on the ten year averages (1988-1997) for each expression of efficiency.

Table 14
Imperial Irrigation District - Ca 1988 - 1997

	Units	Year 1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
1. Net Supply at EHL		2,789,000	2,856,000	2,887,000	2,726,000	2,402,000	2,600,000	2,872,000	2,890,000	2,978,000	2,990,000	2,799,000
2. Farm Headgate Delivery (WST)	Ac-ft/Yr	2,475,000	2,558,000	2,604,000	2,438,000	2,098,000	2,322,000	2,570,000	2,575,000	2,709,000	2,684,000	2,503,300
3. Crop ETc (water bal.)	Ac-ft/Yr	1,861,000	1,861,000	1,880,000	1,859,000	1,738,000	1,795,000	1,862,000	1,820,000	1,853,000	1,988,000	1,851,700
4. Effective Precipitation (water bal.)	Ac-ft/Yr	68,000	59,000	73,000	135,000	210,000	190,000	91,000	79,000	29,000	120,000	105,400
5. Net Irrigation Requirement (water bal.)	Ac-ft/Yr	1,793,000	1,802,000	1,807,000	1,724,000	1,528,000	1,605,000	1,771,000	1,741,000	1,824,000	1,868,000	1,746,300
6. Leaching Requirement (NRCE)	Ac-ft/Yr	310,000	330,000	339,000	346,000	301,000	317,000	365,000	353,000	373,000	345,000	337,900
7. Overall Efficiency	Percent	75.40%	74.65%	74.33%	75.94%	76.14%	73.92%	74.37%	72.46%	73.77%	74.01%	74.50%
8. On-Farm Efficiency	Percent	84.97%	83.35%	82.41%	84.91%	87.18%	82.77%	83.11%	81.32%	81.10%	82.45%	83.36%
9. Conv.& Dist. Efficiency	Percent	88.74%	89.57%	90.20%	89.44%	87.34%	89.31%	89.48%	89.10%	90.97%	89.77%	89.39%

Notes:
1. Net Supply near EHL = AAC Inflow to Canal System - M&I Deliveries.
2. Farm Headgate Delivery = Irrigation Water Delivered within Study Area Reported.
3. Crop ETc = Total Water Consumed on Ag. Land.
4. Effective Precipitation = Rainfall Water Consumption on Ag. Land.
5. Net Irrigation Requirement = Total Irrigation Water Consumption on Ag. Land.
6. Leaching Requirement Determined by NRCE, March 2002.
7. Overall Efficiency = **Net Irrigation Water Requirement +Leaching Requirement / Net Supply.**
8. On-Farm Efficiency = **Net Irrigation Water Requirement + Leaching Requirement / Farm Headgate Delivery.**
9. Conveyance and Distribution Efficiency = **Farm Headgate Delivery / Net Supply.**

COLORADO RIVER INDIAN RESERVATION IRRIGATION DISTRICT

The Colorado River Indian Reservation Irrigation Project is administered by the Bureau of Indian Affairs and is located on both sides of the Colorado River with the majority of the Reservation and irrigated lands located in Arizona. According to the BIA Annual Irrigation Crop Reports of 1994, there are as many as 84,000 acres of irrigable land on the CRIR within Arizona and about 3,590 acres in California. Most of the irrigated farmland is within the floodplain of the Colorado River. About 1,800 acres of irrigated land lies on higher terraces well above the floodplain and are irrigated with water pumped from wells.

Climate

The climate of CRIR has been characterized by the SCS in the Soil Survey of Colorado River Indian Reservation Arizona-California, according to records from the Parker, AZ station. These are summarized below.

Annual Precipitation	4.1 inches/year.
Mean Temperature	73 degrees F.
Growing Season (32 deg. 9/10 years)	257 days.

Specific climate data from the period 1988-1997 were compiled for calculation of reference crop evapotranspiration (ET_o) using the Penman-Monteith method. These were compiled from the records of the AZMET climate station at Parker, Arizona and are shown in Table 15. This table shows the 10 year average, maximum and minimum monthly air temperatures, relative humidity, wind speed, solar radiation, and calculated reference crop evapotranspiration.

Table 15
Colorado River Indian Reservation Climate Station
Average Monthly Figures
AZMET Station Parker Arizona 1988-1997

Month	Air Temperature (F) Max	Min	% Relative Humidity Max	Min	Wind Speed m/s	Rs (MJ/day/m^2)	Rn (MJ/day/m^2)	ETo (mm/day)
Jan	67.2	38.3	80.4	34.0	2.6	11.3	3.4	2.6
Feb	73.0	42.8	78.1	28.6	2.8	15.1	5.7	3.7
Mar	79.0	47.2	77.0	22.6	3.1	20.4	9.1	5.5
Apr	87.5	53.9	63.1	15.1	3.6	25.4	12.2	8.0
May	94.3	61.2	57.8	13.0	3.7	28.4	14.3	9.8
Jun	101.7	67.2	55.8	11.3	3.4	29.9	15.3	10.8
Jul	104.7	73.8	67.1	19.5	3.2	27.9	15.3	10.1
Aug	104.2	74.5	75.8	25.1	2.8	25.5	14.2	8.8
Sep	101.4	67.4	74.2	17.5	2.4	22.4	10.8	7.6
Oct	91.7	55.1	67.4	15.0	2.3	17.9	6.6	5.8
Nov	76.8	43.2	69.7	20.5	2.4	13.3	3.6	3.8
Dec	67.2	36.5	74.7	29.3	2.4	10.7	2.6	2.6

Soils

The majority of irrigated lands within CRIR are made up of the soils found on terraces adjacent to the Colorado River. These soils therefore tend to be mostly alluvial in origin and are considered to be well to excessively drained and of lower water holding capacity. According to the SCS Soil Survey of the Colorado River Indian Reservation, in parts of Lapaz County, Arizona and Riverside and San Bernardino Counties, California, the predominant soils associated with the majority of the CRIR irrigation project are shown in Table 16 below.

Table 16: Descriptions of Soil Series and Complexes of Soil Series Comprising Irrigated Lands within CRIR

a. Gilman-Glenbar-Lagunita	Deep, well drained and somewhat excessively drained level to undulating, loamy and sandy soils; on flood plains
b. Carrizo	Deep, excessively drained, nearly level to gently sloping, very gravelly and sandy soils; on flood plains
c. Superstition-Rositas	Deep, somewhat excessively drained, nearly level to rolling, sandy soils; on stream terraces and sand dunes

The soils of the CRIR irrigation project are somewhat variable, though predominantly coarse and well drained. Leveling of fields in the past has caused the removal and or dispersal of the top layers of the soil profile, which has in turn resulted in the exposure of the more coarse materials below. This has resulted in such rapid deep percolation that proper distribution of irrigation water has been difficult to achieve using surface irrigation methods. Sprinkler irrigation tends to reduce some of these problems and is used to some degree.

Crops

The predominant crops grown by CRIR for the average year within Arizona are shown in Table 17. These crops represent the majority of irrigated lands within the reservation. The records for the period described are not complete (Personnel communication, BIA 1999).

Table 17: Top Ten Crops- Colorado River Indian Reservation, Lapaz, AZ. 1991-1998

Crop	Crop Type	Salt Tolerance	Average Acreage	% of Acres	Running Sum %	Count
Alfalfa	Field	MS	40,508	52.05	52.05	1
Cotton Lint	Field	T	24,269	31.19	83.24	2
Wheat	Field	T	5,348	6.87	90.11	3
Sudan Grass	Field	MT	1,720	2.21	92.32	4
Cantaloupe	Garden	MS	1,201	1.54	93.87	5
Bermuda (Seed)	Field	T	734	0.94	94.81	6
Honeydew	Garden	MS	579	0.74	95.55	7
Onions (dehydrated)	Garden	S	545	0.70	96.26	8
Bermuda (Hay)	Field	T	441	0.57	96.82	9
Oats	Field	MT	440	0.57	97.39	10

Of all the crops grown within the Arizona portion of the Colorado River Indian Reservation during 1991-1998, less than 0.1% were permanent, 4.8% were garden, and 95.1% were field crops. With regard to salinity, the following percentages pertain: 0.7% - no category (according to Maas), 1.4% Sensitive, 2.8 % Moderately Tolerant, 39.6% Tolerant, and 55.% Moderately Sensitive. Acreage of crops grown on CRIR lands within Riverside, California are shown in Table 18.

Table 18: Crops and Acreage- Colorado River Indian Reservation, Riverside County, California, 1993-1998 (records available)

Crop	Crop Type	Salt Tolerance	Average Acreage	% of Acres	Running Sum %	Count
Alfalfa	Field	MS	1,165	78.74	78.74	1
Sudan	Field	MT	3	0.23	78.96	2
Wheat	Field	T	10	0.68	79.64	3
Peanuts	Field	NA	74	4.99	84.63	4
Watermelon	Garden	MS	61	4.15	88.78	5
Cotton Lint	Field	T	33	2.25	94.78	6
Cantaloupe	Garden	MS	77	5.22	100.00	7

The maximum, minimum and average acreage of crops grown within the California portion of the CRIR is 1,774 (1994), 1,260 (1997) and 1,479 (1993-1998) acres respectively, including multiple cropping. Of all crops grown in this portion of CRIR, during 1993-1998, 0.0% were permanent, 2.4% were garden, and 97.6% were field crops. With regard to the salt tolerance of crops, the following percentages pertain: 5.0% - no category (according to Maas), 0.0% Sensitive, 7.9% Moderately Tolerant, 5.9% Tolerant, and 81.2% Moderately Sensitive.

Water Supply

CRIR receives water directly from the Colorado River by surface diversion and from pumped diversions. Lands within California are served exclusively from river pumps and wells. The degree of groundwater supplement is small, as shown by U.S. BOR records of water users.

The quality of irrigation water used by CRIR is that of the Colorado River and would be expected to be of a salinity between that observed at Lee's Ferry, Arizona and Imperial Dam, and is of a higher quality than that diverted at Imperial Dam.

<u>Diversion</u>

Headgate Rock Dam is the main diversion feature serving CRIR lands located in Arizona. The structure is located just north of Parker, Arizona and supplies the main canal and associated laterals. This diversion was first rated by the USGS in 1956. An additional pumped diversion contributes to the irrigation of lands in Arizona.

<u>Conveyance and Distribution</u>

The conveyance and distribution of water within CRIR is operated by the BIA and is for the most part a gravity system. The system has approximately 60 wasteway locations. Furthermore, 15 wasteways spill into subordinate canals at lower elevations, 3 discharge into the river, 2 discharged into the drain system and the remaining portion spilled onto cultivated land. It is believed that the conveyance and drainage system have not changed appreciably since that time. No record of farm delivery was available from the BIA, therefore direct determination of conveyance and distribution efficiency was not possible.

Irrigation and Drainage

The drainage system consists primarily of open drains that are the Main and Mesa drains. The old slough area is also used to convey drain water to La Paz Lake but according to Allsop "This practice has seriously hindered the effective lowering of the [water table by the] Mesa Drain". The drainage channels are 9 to 14 feet in depth and are spaced ¾ of a mile. Slopes vary from 0.0003 to 0.0005 feet per foot.

Since the soils of the CRIR irrigation project are generally regarded as well drained, of higher permeability, and adjacent to the Colorado River, irrigated lands are not normally drainage impacted. However, canal waste into the open drain system has been known to limit drainage efficiency in the project. At the time of Allsop's investigation there were five drainage wells in operation, however it is not known whether drainage wells are still a part of the greater drainage plan for the CRIR irrigation project.

District Water Use Assessment

According to BOR, CRIR reports only flow diverted to the project and not farm headgate deliveries. Flow records and crop production reporting within the Reservation are the responsibility of the Bureau of Indian Affairs (BIA), however the BIA could not provide farm headgate delivery records. Records available from BIA included only a partial record of annual crop acreage. Total diversion and return flow records were available from BOR, from the *Compilation of Records in Accordance with Article V of the Decree of the Supreme Court*. These records show the amount of water diverted and consumed, on which basis it is possible to calculate an expression of overall system efficiency. The average ten year (1988-1997), overall efficiency estimate for CRIR is 62.2 percent. Table 19 summarizes the determination of Overall Efficiency for CRIR. Due to the absence of headgate deliveries, on-farm water use cannot be assessed, since headgate deliveries are necessary to the separation of water received by the farm field and that lost due to inefficiencies associated with the conveyance and distribution system.

Table 19

Colorado River Indian Reservation - Az 1988 - 1997

	Units	Year 1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
1. Annual Cropped Acreage	Acres	*1988 -1990 no acreage reported*			72,379	76,406	73,833	84,055	78,730	78,220	78,382	77,429
8. Diversion at Headgate Rock Dam	Ac-Ft/Yr	625,105	689,610	666,920	633,520	580,360	603,372	664,550	650,840	701,010	616,380	643,167
9. River Pumps	Ac-Ft/Yr	1,187	1,389	5,000	6,000	6,000	-	8,923	13,204	12,829	15,278	6,981
10. Total Diversion	Ac-Ft/Yr	626,292	690,999	671,920	639,520	586,360	603,372	673,473	664,044	713,839	631,658	650,148
11. Return Flow	Ac-Ft/Yr	256,212	263,146	254,695	248,818	229,024	231,479	253,748	238,942	237,501	238,935	245,250
12. Consumptive Use	Ac-Ft/Yr	370,080	427,853	417,225	390,702	357,336	371,893	419,725	425,102	476,338	392,723	404,898
13. Overall Efficiency	%	59.09%	61.92%	62.09%	61.09%	60.94%	61.64%	62.32%	64.02%	66.73%	62.17%	62.20%

Notes:

1. Annual cropped acreage from U.S. Bureau of Indian Affairs Annual Irrigation Report, Colorado River Indian Reservation 1991-1997.

8 - 12., Compilation of Records in Accordance with Ariticle V, U.S. Bureau of Reclamation.

13. Overall Efficiency is calculated as **Total Diversion - Returns / Total Diversion.**

PALO VERDE IRRIGATION DISTRICT

The Palo Verde Irrigation District is located in southeastern Riverside County, California near Blythe, California. The irrigation district is comprised of approximately 120,000 acres of valley and mesa land with an elevation range of 230 to 285 feet above sea level. The project is located on the west side of the Colorado River and is served by the BOR Palo Verde Diversion Project.

Climate

According to the SCS Soil Survey of Eastern Riverside County, PVID gets almost twice the annual precipitation as received in IID and the growing season is 23 days shorter. The specific climate data associated with PVID is as follows:

Annual Precipitation	4.2 inches/year.
Mean Temperature	70 degrees F.
Growing Season	277 days.

Specific climate data from the period 1988-1997 were compiled for calculation of reference crop evapotranspiration (ET_o) using the Penman-Monteith method. These data were compiled from the records of CIMIS climate station # 72 at Palo Verde, California and are shown in Table 20. This table shows the 10 year average, maximum and minimum monthly air temperatures, relative humidity, wind speed, solar radiation, and calculated reference crop evapotranspiration.

Table 20

Palo Verde Climate Station

Average Monthly Figures

Cimis #72 Palo Verde, California 1988-1997

Month	Air Temperature (F) Max	Min	% Relative Humidity Max	Min	Wind Speed m/s	Rs (MJ/day/m^2)	Rn (MJ/day/m^2)	ETo (mm/day)
Jan	67.0	36.1	80.0	33.1	1.8	10.8	3.4	2.1
Feb	73.2	40.6	77.1	29.8	2.0	14.5	5.7	3.0
Mar	79.4	44.9	73.1	23.5	2.2	20.1	9.1	4.6
Apr	86.2	51.2	70.2	21.3	2.4	25.5	12.3	6.1
May	92.4	58.1	67.5	22.8	2.5	27.9	14.7	7.2
Jun	100.6	65.0	62.3	22.2	2.4	29.3	16.0	8.3
Jul	105.8	73.8	63.8	29.1	2.8	27.5	15.2	8.5
Aug	104.1	74.7	69.3	30.9	2.5	25.4	13.5	7.6
Sep	100.2	66.7	75.0	28.2	2.0	22.1	10.7	6.1
Oct	89.0	53.1	77.3	24.7	1.7	16.8	7.0	4.3
Nov	75.1	41.5	76.5	25.9	1.8	12.6	3.9	2.8
Dec	66.0	34.5	79.1	32.7	1.7	10.4	2.8	1.9

Soils

Soils of PVID are described in the U. S. Department of Agriculture *Soil Survey of The Palo Verde Area, California* 1926, Walter W. Weir and R. Earl Storie, *Soils of a Portion of Palo Verde Valley*, 1947 and U.S. Department of Agriculture, Soil Conservation Service, *Soil Survey of Eastern Riverside County*, 1974. The soils are summarized in Table 21.

Table 21: Descriptions of Soil Series and Complexes of Soil Series Comprising the Valley Soils of PVID Based on Descriptions found in 1927 Survey.

a. Carrizo	Coarse textured soils in narrow washes from adjacent desert.
b. Imperial	Relatively impervious soils to depths of 6 feet.
c. Holtville	Relatively impervious surface soils over permeable subsoils.
d. Gila	Recently deposited alluvial soils.
e. Meloland	Loose, permeable wind modified soils.
f. Rositas	Deep, excessively drained sands on old terraces and dunes.

The valley soils of PVID form a mosaic made up of six soil series which are Carrizo, Imperial, Holtville, Gila, Meloland, and Rositas soils. These are soils that have developed along the Colorado River as a result of alluvial processes. The valley floor is about 1 to 3 miles wide, beginning at the Palo Verde Diversion and continuing to the Imperial County line. Most of the area is only a few feet above the normal water surface elevation of the river, making irrigated agriculture impractical until the construction of the levee system and Hoover Dam. The water table is usually about six feet from the surface. The soils of the Palo Verde Valley are a mix of soils comprising a range of textures from clay to coarse sand. Permeability of these soils is expected to range similarly from low to high. The water table of PVID is naturally high, except for artificial drainage. Before drainage systems were installed, the groundwater table fluctuated due to variations in river flow. Such a response of groundwater depth to river flow suggests good overall drainability of district lands. According to Aaron Quist of Stansworth Agricultural Consulting, located in Blythe, California, PVID soils are naturally well drained soils but do occasionally exhibit longitudinal streaks of heavy, low permeability soil. Also indicated by Mr. Quist was that PVID soils are about one-half the salinity of IID soils. (Aaron Quist (personal conversation, July 2003)).

Crops

A complete history of PVID's crop reports was obtained for the period of record 1988-1997, as were total diversion and return flow records. Records of farm headgate deliveries were not available and according to the BOR, PVID does not provide the requested annual summaries of crops grown or water conveyed or distributed within the District. According to the available crop reports, the maximum, minimum, and average acreage irrigated by PVID is 115,658 (1989), 82,500 (1993) and 97,129 (1988-1997) acres of land respectively, including multiple cropping. Table 22 below summarizes the crops comprising the top ten crops grown over the period of record by acreage.

Of all the crops grown within PVID during 1988-1997, 1.6% were permanent, 11.9% were garden, and 86.5% were field crops. With regard to salt tolerance of crops, the following percentages pertain: 0.3% - no category (according to Maas), 1.7% Sensitive, 14.4% Moderately Tolerant, 17.4% Tolerant, and 66.2% Moderately Sensitive.

Table 22: Total Crops and Acreage- Palo Verde Irrigation District, Riverside County, California, 1988-1997

Crop	Crop Type	Salt Tolerance	Average Acreage	% of Acres	Running 1.1.1.1.1.1 u m %	Count
Alfalfa	Field	MS	51,161	49.35	49.35	1
Cotton (short)	Field	T	14,820	14.30	63.65	2
Wheat	Field	MT	7,674	7.40	71.05	3
Sudan	Field	MT	5,499	5.26	76.31	4
Alfalfa Pasture	Field	MS	4,299	4.15	80.46	5
Cantaloupes	Garden	MS	3,768	3.63	84.09	6
Lettuce	Garden	MS	3,795	3.66	87.09	7
Oats	Field	MT	2,018	2.08	89.17	8
Citrus	Permanent	S	1,459	1.41	90.58	9
Bermuda Grass	Field	T	1,422	1.37	91.95	10

Water Supply

PVID is served exclusively by the Colorado River. As with CRIR, the water quality of irrigation water used by PVID is of a quality between that of the Colorado River at Lee's Ferry, Arizona and Imperial Dam.

Diversion

The Palo Verde diversion dam and levee works are located 9 miles northeast of Blythe and were built by the USBR, although, operation was turned over to PVID in 1957. Operation and maintenance of the levee system was turned over to the Bureau of Indian Affairs in 1958 (USBR website 2000). The dam is a semipervious sand, gravel, and rockfill structure of 1,300 feet in length. The width of the crest is 20 feet and the maximum height of the dam above the streambed is 46 feet. Upstream and downstream slopes are 4:1. Diversion of water to PVID is accomplished by means of a diversion dam that under normal conditions maintains a constant water surface elevation of 283.5 feet above mean sea level. The diversion capacity is 1,800 cfs which is accommodated by 3-50 foot bays located on the right abutment. The spillway is also located in the right abutment.

Conveyance and Distribution

The conveyance and distribution systems were built privately. Most lands are irrigated using surface irrigation methods such as furrow and border strip. The U.S. Bureau of Reclamation does not receive records of farm deliveries from PVID and therefore direct estimate of conveyance and distribution efficiency is not possible.

Irrigation and Drainage

The Olive Lake Drain, Anderson Drain, and the Palo Verde Outfall Drain comprise most all drainage flow from the project back to the Colorado River via the Palo Verde Outfall Drain. This outfall discharges into an old channel of the Colorado River and then to the Colorado River at the Cibola Wildlife Refuge. (CRWQCB 2003). The flow of the outfall in 2002 ranged from 370 cfs to 639 cfs, with an average flow of 524 cfs. However, irrigation contributes to shallow groundwater as well as to the river. As with irrigated lands of the CRIR irrigation project, PVID lands are not generally considered drainage-impacted lands. Most fields within PVID are irrigated as dead-level basins of 10 to 20 acres and thus produce no tailwater, as water is impounded on relatively permeable soils (Aaron Quist (personal conversation, July 2003)). According to CRWQCB, PVID allows irrigators to divert surface runoff into drains, however the drains contain mainly groundwater seepage. This is also the case for the Yuma Irrigation district, where level basins are small, about 15 to 20 acres in area and are used primarily for production of crops like lettuce. The Yuma Irrigation District soils have EC_e values (electrical conductivities of the soil extract) of about 1 to 2 dS/m. Irrigation drainage on the Yuma projects is accomplished by means of shallow groundwater pumping, which is similar to the system used on WMID. The Yuma projects do not return drainage water to the Colorado River, but rather it is conveyed from each district via canal, to the Colorado River Desalinization Plant, near Mexico, when operational. During times of non-operation, the drainage water is discharged into the Colorado River near Mexico. (Marcos Moore (personal conversation, July 2003)).

PVID WATER USE ASSESSMENT

According to the BOR, PVID reports only the flow diverted to the project and does not report farm headgate deliveries, it is therefore difficult to review the water use within the on-farm system. Based on the BOR's *Compilation of Records in Accordance with Article V of the Decree of the Supreme Court,* it is possible to calculate an expression of overall system efficiency based on the amount of water diverted and consumed, in contrast to what is returned to the river as return flow. The estimated of overall efficiency for PVID is 48 percent. Table 23 summarizes water use and Overall Efficiency for PVID for the 1988-1997 period of record.

Table 23
Palo Verde Irrigation District 1988 - 1997

	Units	Year 1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
1. Annual Cropped Acreage	Acres	109,586	115,658	110,658	105,544	103,852	82,500	96,978	105,186	103,726	102,990	103,668
8. Total Diversion	Ac-Ft/Yr	898,650	935,426	917,480	851,920	768,160	737,100	800,370	861,800	953,010	917,520	864,144
9. Return Flow	Ac-Ft/Yr	454,829	483,377	457,865	438,955	433,471	402,633	417,894	435,201	459,438	495,669	447,933
10. Consumptive Use	Ac-Ft/Yr	443,821	452,049	459,615	412,965	334,689	334,467	382,476	426,599	493,572	421,851	416,210
11. Overall Efficiency	%	49.39%	48.33%	50.10%	48.47%	43.57%	45.38%	47.79%	49.50%	51.79%	45.98%	48.03%

Notes:
1. Annual cropped acreage from Palo Verde Irrigation District Reports 1988-1997.
8 - 10., Compilation of Records in Accordance with Ariticle V, U.S. Bureau of Reclamation.
11. Overall Efficiency is calculated as Total Diversion - Returns / Total Diversion.

WELLTON-MOHAWK IRRIGATION DISTRICT

The Wellton-Mohawk Irrigation District is part of the BOR's Gila Project which is divided into the Wellton-Mohawk Division and the Yuma Division. The Wellton Mohawk Division begins about 12 miles east of the city of Yuma, Arizona and continues upstream on both sides of the Gila River for about 45 miles. Full development of the Wellton-Mohawk Division would comprise about 65,000 acres, the lands of which are at elevations between 150 and 340 feet above sea level. Originally the project was 75,000 acres but was reduced as a result of the Colorado Basin Salinity Control Act of 1974. The project authorization limits the diversions from the Colorado River to 600,000 acre-feet annually, which is divided equally between WMID and Yuma Irrigation District. Power for the project is provided through the Parker Davis transmission system.

Climate

The specific climate data associated with WMID, as characterized in the 1980 SCS Soil Survey of Yuma-Wellton Area are as follows:

Annual Precipitation	2.9 inches/year.
Mean Temperature	71 degrees F.
Growing Season (32 deg. 9/10 years)	259 days.

Specific climate data from the period 1988-1997 were compiled for calculation of reference crop evapotranspiration (ET_o) using the Penman-Monteith method. These data were compiled from the records of the AZMET climate station at Yuma Valley, Arizona and are shown in Table 24. This table shows the 10 year average, maximum and minimum monthly air temperatures, relative humidity, wind speed, solar radiation, and calculated reference crop evapotranspiration.

Table 24
Wellton Mohawk Climate Station
Average Monthly Figures
AZMET Station Yuma Valley, Arizona 1988-1997

Month	Air Temperature (F) Max	Air Temperature (F) Min	% Relative Humidity Max	% Relative Humidity Min	Wind Speed m/s	Rs (MJ/day/m^2)	Rn (MJ/day/m^2)	ETo (mm/day)
Jan	68.2	42.3	78.9	30.0	2.8	11.6	3.6	3.2
Feb	74.0	46.0	77.3	25.5	2.7	15.3	5.9	3.9
Mar	79.8	49.2	77.0	21.0	2.5	21.0	9.5	5.3
Apr	86.7	54.2	72.6	16.0	2.6	25.9	12.7	6.8
May	93.5	60.4	67.3	13.0	2.7	29.1	14.9	8.3
Jun	102.0	66.5	59.3	10.4	2.5	30.1	15.4	9.5
Jul	106.0	75.1	65.3	16.2	2.6	27.8	15.1	9.6
Aug	105.2	77.7	70.7	21.6	2.6	25.6	14.1	9.0
Sep	101.5	71.9	71.6	18.7	2.4	22.5	11.1	7.9
Oct	91.3	60.6	77.1	17.6	2.4	18.1	7.3	6.0
Nov	77.0	48.7	76.2	21.8	2.6	13.2	4.1	4.2
Dec	67.2	41.3	79.3	29.8	2.6	10.8	3.0	3.0

Soils

As with PVID, the WMID project is comprised of both valley and mesa areas with most of the irrigated area occupying the valley. The SCS Service Soil Survey of the Yuma-Wellton area was compiled in 1980 and covers the Wellton-Mohawk Project. These soils tend to be much coarser than those encountered in IID and are naturally well drained on the basis of the soil permeability. However, district drainage has been negatively impacted by rising water tables resulting from accumulation of irrigation drainage water within the alluvium underlying many farm fields. The majority of irrigated lands within the project consist of the following soils as shown in Table 25.

Table 25: Description of Soil Series and Complexes of Soil Series Comprising Irrigated Lands within WMID.

a. Indio-Ripley-Lagunita	Deep, nearly level to gently sloping, well drained and somewhat excessively drained, silty and sandy soils: on flood plains, low terraces, and alluvial fans and in drainageways
b. Dateland-Wellton	Deep, nearly level, well drained, loamy soils; on old alluvial fans and high terraces
c. Ligurta-Cristobal-Carrizo	Deep, nearly level, well drained and excessively drained, gravelly and very gravely soils: on alluvial fans, low terraces, and flood plains
d. Tremant-Harqua-Rositas	Deep, nearly level, well drained and somewhat excessively drained, gravelly and sandy soils; on terraces, alluvial fans, and sand dunes

Crops

The records of cropping within the WMID are complete in that the District reports annually to the BOR. The BOR's *Crop Production and Water Utilization Data* records show that WMID irrigates maximum, minimum, and average irrigated acreage of 85,267 (1998), 69,462 (1992), and 80,467 (1989-1997) acres, including multiple cropping. Table 26 summarizes the top ten crops grown by the district for the period of record.

Table 26: Top Ten Crops and Acreage- Welton-Mohawk Irrigation District, Yuma County, Arizona, 1989-1997

Crop	Crop Type	Salt Tolerance	Average Acreage	% of Acres	Running 1.1.1.1.1.1 u m %	Count
Alfalfa hay	Field	MS	18,355	22.94	22.94	1
Lettuce	Garden	MS	17,704	22.13	45.07	2
Cotton Lint	Field	T	14,513	18.14	63.21	3
Wheat	Field	MT	13,067	16.33	79.54	4
other hay	Field	NA	5,472	6.84	86.38	5
Seed	Field (assumed)	NA	4,045	5.06	94.11	6
Citrus	Permanent	S	1,390	1.74	94.96	7
Nuts	Permanent	S	745	0.93	95.74	8
Cauliflower	Garden	MS	683	0.85	96.48	9
Other Field	Field	NA	624	0.78	95.74	10

Of all crops grown in within WMID during 1989-1997, 2.7% were permanent, 26.1% were garden, and 71.2% were field crops. With regard to salt tolerance of crops, the following percentages pertain, 13.0% - no category (according to Maas), 2.8% Sensitive, 16.5% Moderately Tolerant, 18.5% Tolerant, and 49.2% Moderately Sensitive.

Water Supply

Colorado River water is diverted to WMID from the east abutment of the Imperial Dam from where it flows through a desilting works and then into the Gila Main Canal. The Colorado River is the only source of water used by the district. The quality of irrigation water available to WMID is more deteriorated than that available to CRIR and PVID, but close to that available to CVWD and IID, the latter of which also receive their water from Imperial Dam diversions.

Diversion

The Gila Gravity Main Canal was completed in 1939 and is unlined. The headworks of the Gila Gravity Main Canal have three sets of outlets, each with three radial gates which discharge a total of 2,200 cfs into the desilting works. From this point, the canal flows about 18.5 miles to where WMID takes its share by means of the Wellton-Mohawk Canal. The remaining portion of the water continues for another two miles to the Yuma Mesa Pumping Plant, which serves the Yuma Project.

Conveyance and Distribution

The Wellton-Mohawk Canal is approximately 18.5 miles long and has a capacity of 1,300 cfs. This canal was completed in 1951 and has both lined and unlined sections. There are three pumping plants on the Wellton-Mohawk Canal which have a combined lift of 170 feet. In addition to the main pumping stations, there are 15 smaller pumping plants throughout the project. The Wellton-Mohawk Canal bifurcates into the Wellton Canal and the Mohawk Canal, which are 19.9 miles long and 300 cfs, and 46.8 miles long and 900 cfs capacity respectively. These canals were completed in 1953 and both are concrete lined. Other subordinate canals include the Texas Hill Canal and the Dome Canal. The Texas Hill Canal is 9.8 miles in length with a capacity of 125 cfs and it takes water from the Mohawk Canal. The Dome Canal is 11 miles in length with a capacity of 220 cfs and it takes water from the Wellton-Mohawk Canal. The Texas Hill Canal was completed in 1956 and is concrete lined. The Dome Canal was completed in 1954 and is concrete lined.

Irrigation and Drainage

Most lands are irrigated using surface irrigation methods such as furrow and border strip. Historically, farms within WMID relied on pumped shallow groundwater but after years of farming, these wells became increasingly saline. The Gila Project provided surface water in 1957 which alleviated these problems but resulted in a high water table. The problem of high water restricted the rooting depth of crops and was addressed by means of drainage wells that originally discharged into the Gila River Channel. The Gila River is highly diverted upstream and flows only during extreme flood events and does not normally reach the Colorado River. Discharge of drain water into the Gila River channel was a limited solution to high water that was also becoming more saline. The Wellton-Mohawk Conveyance Channel was completed in 1961 to convey saline drain water from 67 drainage wells to the vicinity of the Colorado River. That drain water is now conveyed via canal to Mexico, thus bypassing the Colorado River.

WMID WATER USE ASSESSMENT

Records associated with WMID's water use are complete and according to the BOR WMID provides a statement of water usage that includes net supply, transportation losses, municipal/industrial and water delivered to farms. Net supply figures agree with the numbers reported by the BOR in their *Compilation of Records in Accordance with Article V of the Supreme Court.* The combination of these records and the water utilization data allow for the calculation of estimates of various expressions of efficiency. Table 27 summarizes water use and efficiency for WMID for the period 1988-1997. This table represents a determination of water use on the basis of annual records of acreage, diversion, delivery, and crop evapotranspiration. Return flow is reported for WMID. Drainage water that is collected is routed to Mexico via canal. There are obviously losses associated with the collection, conveyance and processing of drain water. It is not known if these losses are reflected in the return flow credited to Wellton Mohawk by BOR. Net supply figures reported are registered below the diversion within the Gila Gravity Main.

Since return flows are reported it is possible to make a direct determination of overall efficiency. The overall efficiency for WMID can be calculated as Total Diversion - Return - DCM&I / Total Diversion - DCM&I. Additional estimates of overall efficiency were made on the basis of estimated net irrigation requirement and net supply less DCM&I. The estimated 10 year average (1988-1997) efficiencies are 67.6, 92.2 and 73.5 percent for overall, conveyance/distribution and on-farm categories. Annual estimated efficiency values are shown in Table 27.

Table 27

Wellton-Mohawk Irrigation District 1988 - 1997

	Units	Year 1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
1. Annual Cropped Acreage	Acres	80,006	75,858	76,284	79,748	84,309	69,462	78,489	82,252	83,699	84,690	79,480
8. Total Diversion	Ac-Ft/Yr	450,720	459,232	453,807	447,309	377,094	299,981	371,689	388,701	415,131	415,190	407,885
9. Return to Colorado River	Ac-Ft/Yr	128,602	137,024	138,170	147,270	117,902	130,354	119,438	141,292	140,710	102,676	130,344
10. Consumptive Use	Ac-Ft/Yr	321,655	321,793	314,557	299,004	258,399	168,751	251,438	246,554	273,516	311,610	276,728
11. Farm Headgate Delivery	Ac-Ft/Yr	386,852	392,183	397,836	409,987	357,440	287,348	351,402	372,050	391,136	392,345	373,858
12. Overall Efficiency	%	71.44%	70.14%	69.48%	67.00%	68.67%	56.42%	67.80%	63.57%	66.03%	75.22%	67.58%
13. Conv.& Dist. Efficiency	%	85.92%	85.48%	87.88%	91.87%	94.99%	96.07%	94.75%	95.93%	94.43%	94.70%	92.20%
14. On-Farm Efficiency	%	83.15%	82.05%	79.07%	72.93%	72.29%	58.73%	71.55%	66.27%	69.93%	79.42%	73.54%

Notes:

1. Annual cropped acreage from Bureau of Reclamation Crop Production and Water Utilization Data reports 1988-1997.

8. and 9. from Compilation of Records in Accordance with Article V., U.S. Bureau of Reclamation 1988-1997.

10. Consumptive Use = **(Total Diversion - Return - DCM&I).**

11. Farm Headgate Delivery from Bureau of Reclamation, Crop Production and Water Utilization Data reports 1988-1997.

12. Overall Efficiency = **Net Supply / Total Diversion - DCM&I.**

13. Conveyance and Distribution Efficiency = **Farm Headgate Delivery / Total Diversion - DCM&I.**

14. On-Farm Efficiency = **Overall Efficiency / Conveyance and Distribution Efficiency.**

COACHELLA VALLEY WATER DISTRICT

The Coachella Valley Water District is part of the BOR's All American Canal System Project which diverts water from Imperial Dam to IID and to CVWD. This project was authorized under the Boulder Canyon Project Act of 1928. Water diverted from Imperial Dam enters the All American Canal that flows west toward the basin of the Salton Sea. CVWD, like IID does not return unused water to the Colorado River. The use of water within CVWD includes agricultural as well as municipal water use, with a significant amount of water going to playing fields and golf courses. The irrigated lands of CVWD exist at elevations between 75 feet above and 229 feet below sea level. CVWD provides water-related services to an area of over 600,000 acres. As part of the contract between BOR and CVWD, Colorado River water can be used only within an area known as Improvement District #1 (ID #1). Within the improvement district, surface water is used conjunctively with groundwater. Outside ID #1, irrigation is accomplished only by means of groundwater.

According to CVWD, "Improvement District #1 is the area that has been paying taxes that finance the Coachella Canal. That 85% of farms [within ID #1] are using canal water and that 15% are using well water. That ID #1 comprises an area of about 78,530 acres of which 58,033 acres are being farmed and that 27,827 acres or 48% of lands use drip irrigation" (CVWD 1997 Severe Groundwater Overdraft – Possible Strategies and Opportunities).

Climate

The climate of Coachella Valley at Mecca, as characterized by the SCS Soil Survey of Coachella Valley Area is described as follows:

Annual Precipitation	3.07 inches/year.
Mean Temperature	71.8 degrees F.
Growing Season (>32 deg. 8/10 years)	293 days.

Specific climate data from the period 1988-1998 were compiled for calculation of reference crop evapotranspiration (ETo) using the Penman-Monteith method. These data were compiled from the records of CIMIS climate station # 50 at Thermal, California and are shown in Table 28. This table shows the 10 year average, maximum and minimum monthly air temperatures, relative humidity, wind speed, solar radiation, and calculated reference crop evapotranspiration.

Table 28
Coachella Valley Climate Station
Average Monthly Figures
Cimis #50 Thermal, Coachella Valley, California 1988-1997

Month	Air Temperature (F) Max	Air Temperature (F) Min	% Relative Humidity Max	% Relative Humidity Min	Wind Speed m/s	Rs (MJ/day/m^2)	Rn (MJ/day/m^2)	ETo (mm/day)
Jan	69.0	40.1	80.1	32.7	1.6	11.1	3.4	2.2
Feb	74.1	44.7	74.1	29.4	2.0	14.6	5.6	3.2
Mar	79.4	50.2	71.0	25.7	2.4	19.9	9.0	4.8
Apr	85.9	56.7	64.2	21.9	3.1	24.6	12.3	7.0
May	91.4	63.4	62.3	23.8	3.5	27.6	14.7	8.3
Jun	99.2	68.4	60.6	22.0	3.3	29.3	16.0	9.4
Jul	103.2	74.1	62.9	25.4	2.8	27.2	15.2	9.0
Aug	102.6	74.4	63.8	25.8	2.6	24.7	13.5	8.3
Sep	98.8	68.8	67.9	24.3	2.4	21.5	10.6	6.9
Oct	89.7	57.7	69.0	23.9	2.1	17.4	7.0	4.9
Nov	77.4	45.8	70.5	24.7	1.8	12.9	3.8	3.0
Dec	68.8	38.7	77.3	32.7	1.6	10.4	2.7	2.1

Soils

Areas within CVWD that receive water from the Colorado River are encompassed by Improvement District #1, other areas are not entitled to Colorado River water and must use groundwater exclusively. The dominant soils of Improvement District #1 are quite different from those that dominate the irrigated lands of IID, in that the majority of the soils of ID #1 are considerably coarser in texture and are easily drained. The soils of ID #1 occur largely as complexes of specific soil series, the following of which predominate the irrigated lands of CVWD. According to the SCS, soil complexes consist of areas of two or more soils, so intermingled or so small in size that they cannot be shown separately on the soil map. These are summarized below in Table 29.

Table 29: Description of Soil Series and Complexes of Soil Series Comprising Lands within ID #1 of CVWD

a. Carsita-Myoma-Carizo	Nearly level to moderately steep, somewhat excessively drained or excessively drained sands, fine sands, gravelly sands, cobbly sands and stony sands on alluvial fans and valley fill.
b. Myoma-Indio-Gilman	Nearly level to rolling, somewhat excessively drained to moderately well drained fine sands in dune areas and loamy fine sands, very fine sandy loams, fine sandy loams, and silt loams on alluvial fans
c. Gilman-Coachella-Indio	Nearly level to rolling, somewhat excessively drained to moderately well drained fine sands, fine sandy loams, silt loams, loamy fine sands, and very fine sandy loams on alluvial fans.
f. Salton-Indio-Gilman	Nearly level, somewhat poorly drained to well drained silty clay loams, very fine sandy loams, fine sandy loams, and silt loams in lacustrine basins.

Each soil series has its own distinguishable characteristics that define it physically and taxonomically. The permeability, permeability group, and corresponding acreage are listed in Table 30 for the specific soil series that comprise the soils found within the Improvement District # 1 of CVWD.

Table 30 **Acreage of Lands within Improvement District #1 based on Permeability of Limiting Permeability by Soil Type**

Map_Unit	Donimate_Soil	Minor Description	Acreage (ac)	Permeability Range (Low and High)		Limiting Permeability	Group Acreage
IcA	Imperial	Silty Clay, Wet, 0 to 2 Percent Slopes	15	0.06	0.20	0.06	
Sa	Salton	Fine Sandy Loam	485	0.06	0.20	0.06	
Sb	Salton	Silty Clay Loam	4,565	0.06	0.20	0.06	
CoB	Chuckawalla	Very Gravelly Sandy Clay Loam, 2 to 5 Percent Slope	18	0.06	0.20	0.06	5,082
GdA	Gilman	Fine Sandy Loam, Moderatly fine substratum, 0 to 2 Percent Slopes	680	0.60	2.00	0.60	
GbA	Gilman	Fine Sandy Loam, 0 to 2 Percent Slope	10,777	0.60	2.00	0.60	
GbB	Gilman	Fine sandy Loam, 2 to 5 Percent Slope	544	0.60	2.00	0.60	
GcA	Gilman	Fine Sandy Loam, Wet, 0 to 2 Percent Slopes	20,750	0.60	2.00	0.60	
GeA	Gilman	Silt Loam, 0 to 2 Percent Slope	1,379	0.60	2.00	0.60	
GfA	Gilman		3,204	0.60	2.00	0.60	
Ip	Indio	Fine sandy Loam	1,315	0.60	2.00	0.60	
Ir	Indio	Fine Sandy Loam, wet	5,041	0.60	2.00	0.60	
Is	Indio	Very Fine Sandy Loam	6,476	0.60	2.00	0.60	
It	Indio	very Fine sandy Loam, wet	18,515	0.60	2.00	0.60	
CpA	Coachella	Fine Sand, 0 to 2 Percent Slope	7,009	0.60	2.00	0.60	
GaB	Gilman	Loamy fine sand, 0 to 5 Percent Slopes	556	2.00	6.00	2.00	
CpB	Coachella	Fine Sand, Hummocky, 2 to 5 Percent Slope	272	2.00	6.00	2.00	
CrA	Coachella	fine Sand, Wet, 0 to 2 Percent Slopes	6,005	2.00	6.00	2.00	
CsA	Coachella	Fine Sandy Loam, 0 to 2 Percent Slope	1,756	2.00	6.00	2.00	84,279
CdC	Caristas	Stony Sand 2 to 9 Percent Slope	9,839	6.00	20.00	6.00	
ChC	Caristas	Cobbly Sand 2 to 9 Percent Slope	3,032	6.00	20.00	6.00	
CkB	Caristas	Fine Sand, 0 to 5 Percent Slope	422	6.00	20.00	6.00	
MaB	Myoma	Fine sand, 0 to 5 Percent Slopes	18,168	6.00	20.00	6.00	
MaD	Myoma	Fine sand, 5 to 15 Percent Slopes	8,140	6.00	20.00	6.00	
McB	Myoma	Myoma fine sand, wet 0 to 5 Percent Slopes	3,700	6.00	20.00	6.00	
CcC	Carrizo	Stony Sand, 2 to 9 Percent Slope	255	20.00	20.00	20.00	43,555
		Total Acres	132,917				132,917

The soils of the total land area within ID #1 of CVWD are characterized by the permeability groups shown in Table 31.

Table 31: Soils Permeability Groups and Acreage of Lands within ID #1

Permeability Group	Acres	Percent Represented
High	43,555	32.77%
Medium	84,279	63.41%
Low	5,082	3.82%
Total	132,916 acres	100.0%

It can be seen that medium and high permeability soils predominate Improvement District #1 of CVWD. This of course has major implications with regard to agricultural and irrigation practices.

Crops

Predominant crops grown in the Coachella Valley include oranges, lemons, grapefruit, table grapes, and dates. Row crops include carrots, corn, tomatoes, onions, squash, bell peppers, radishes, and leaf lettuce. Other crops include alfalfa and cotton.

The maximum, minimum, and average irrigated acreage within CVWD is 72,228 (1990), 65,034 (1994), and 69,869 (1989-1997) acres respectively, including multiple cropping. Table 32 summarizes the top ten crops, by acreage, grown during the period of record.

Table 32: Top Ten Crops by Acreage- Coachella Valley County Water District, Riverside County, California, 1989-1997.

Crop	Crop Type	Salt Tolerance	Average Acreage	% of Acres	Running Sum %	Count
Citrus	Permanent	S	15,643	22.3	22.32	1
Grapes	Permanent	MS	14,843	21.18	43.50	2
Dates	Permanent	T	6,201	8.8	52.35	3
Corn	Garden	MS	5,050	7.21	59.56	4
Lettuce	Garden	MS	3,257	4.65	64.21	5
Other Veg	NA	NA	3,176	4.53	68.74	6
Alfalfa Hay	Field	MS	2,140	3.05	71.79	7
Sudan Hay	Field	MT	1,888	2.69	74.48	8
Broccoli	Garden	MS	1,831	2.61	77.09	9
Carrots	Garden	S	1,760	2.51	79.60	10

Of all crops grown within CVWD during 1989-1997, 56.7% were permanent, 34.4% were garden, and 8.9% were field crops. With regard to salt tolerance of crops, the following percentages pertain: 9.1% - no category (according to Maas), 29.5% Sensitive, 2.7% Moderately Tolerant, 10.2% Tolerant, and 48.5% Moderately Sensitive. NRCE estimated a leaching requirement of 9.7 percent for CVWD based on the salt tolerance of the crops listed above and the electrical conductivity of water supplied.

It can be seen that CVWD produces more permanent and garden crops than the other districts presented. These crops have a greater sensitivity to salt. The dominant types of crops grown by CVWD generate greater income on a per acre basis than those grown by IID or the other districts in this comparison. Groundwater quality is likely a factor in crop selection, since an unknown percentage of the agricultural water supply for CVWD is derived from groundwater, which is of better quality than the surface water from the Colorado River. Additionally, the greater permeability of soils within CVWD, allows more efficient leaching of salts from CVWD fields. Because overall water quality and favorable drainage conditions allow for the production of higher value crops, the costs associated with irrigation systems and management employed in the Coachella Valley can of course be greater on a per acre basis. This has significant impact on the types of irrigation systems that can be economically employed.

Water Supply

CVWD's irrigation system receives its surface water by gravity. Colorado River water is diverted to CVWD and IID from the west abutment of the Imperial Dam from where it flows through a desilting works and then into the All American Canal. Prior to the completion of the Coachella Canal in 1948, Coachella Valley was irrigated exclusively by means of groundwater wells. After completion of the Coachella Canal, water was diverted from the All American Canal, which previously served only IID. CVWD continues to use groundwater for irrigation throughout the greater district and a portion of the water used for irrigation within ID #1 is groundwater as well. Because CVWD is not responsible for groundwater supplies, and California does not require annual groundwater pumpage to be reported, it is difficult to estimate the total groundwater produced and used within ID #1. Surface water received by the District via Coachella Canal enters a closed pipeline system that facilitates the flexibility with which water can be supplied.

The quality of irrigation water derived from the Colorado River is similar to IID and WMID and is more deteriorated than that available to CRIR and PVID. Groundwater quality, as with quantity, within CVWD, is difficult to ascertain but it is most likely better than the quality of the Colorado River water.

<u>Diversion</u>

The main diversion at Imperial Dam serves the All American Canal from which the Coachella Canal diverts its water at Drop #1 at a rate of up to 2,500 cfs. The average diversion available to CVWD, at Drop #1 is 320,443 acre-feet per year.

<u>Conveyance and Distribution</u>

From Drop #1, the canal flows 123 miles north-northwest to ID #1. This is the only area of land authorized to receive Colorado River water. Originally, the first 86 miles of canal were unlined, but due to extreme losses (about 28%), Congress provided funding for the lining of the first 49 miles of the canal as part of the Colorado River Basin Salinity Control Project in 1974. Presently, all but 32 miles of the canal are lined. Operation of the Coachella Canal and appurtenant works downstream of station 26+04 was transferred to CVWD in 1949. CVWD's distribution system was designed and constructed by the BOR. The system consists of 459 miles of mostly buried, concrete, gravity flow pipelines and a few small pumping plants to serve lands at higher elevations. Operation of the distribution system was turned over to CVWD in 1954. The average efficiency associated with the CVWD's conveyance and distribution is 89%, for 1988-1997.

Irrigation and Drainage

Most lands within CVWD are irrigated using trickle and micro sprinkler irrigation with some surface irrigation such as furrow and border strip. The coarse soils of CVWD are well suited to drip and sprinkler irrigation. These high cost irrigation systems are justified because of the soils, improved water quality, and the high value associated with crops grown in CVWD. Drainage within the irrigated portions of Coachella Valley is largely accomplished by means of tile drains and collector pipes which discharge into the Salton Sea. It is important to note that because of the high permeability of the CVWD soils most of the return flow to the Salton Sea cannot be seen or measured. In contrast, the heavy soils within IID dictate that the return flow is largely via surface drains that can be seen and measured.

CVWD WATER USE ASSESSMENT

CVWD provides a statement of water usage to the BOR that includes net supply, DCM&I, and farm headgate deliveries. Net supply figures agree with the numbers reported by the BOR in their *Compilation of Records in Accordance with Article V of the Supreme Court*. As stated previously, Improvement District #1 uses both Colorado River Water and Groundwater, though groundwater contributions to irrigation water supply are not reported by CVWD. Because estimates of irrigation efficiency require knowledge of total irrigation water supply, such estimates are sensitive to groundwater contributions. Various researchers have estimated of groundwater contribution to irrigation of ID #1. It has been estimated by CVWD that groundwater constitutes 15% of surface water supply, though this estimate is believed to be less than the actual base on water balance analysis The basis for this estimation is a document entitled *Coachella Valley Water Problem: Severe Groundwater Overdraft "Possible Strategies and Opportunities:* 1997 CVWD. Table 33 summarizes water use and efficiency estimates for CVWD within ID #1. This table represents a determination of water use on the basis of annual records of diversion, delivery, crop evapotranspiration, estimated leaching requirements, and estimated actual irrigated acreage. Acreage as reported by BOR is believed to be high, therefore Boyle's estimate of approximately 52,000 acres was used across the study period. As with IID, CVWD generates no return flow to the Colorado River and therefore none is reported. According to the BOR, the reported net supply figures are representative of flows near Drop #1 at mile marker 0.20 on the Coachella Canal.

For CVWD, overall efficiency was estimated on the basis of estimated net irrigation requirement and net supply less DCM&I. The adjusted estimate of NIR from this analysis, using Boyle's cropped acreage figures, is about 4.5 acre-feet per year including an adjusted leaching requirement 9.7% using Equation 1, stated previously (Rhoades, 1974).

Direct estimates of conveyance and distribution efficiency and on-farm efficiency were possible for CVWD because of the existence of records specifying farm headgate deliveries. On the basis of this record and that of net supply it is possible to estimate the efficiency of the conveyance and distribution system. Annual on-farm efficiency determinations were possible by means of relating farm headgate deliveries and estimated net irrigation water requirements. Average overall, conveyance/distribution, and on-farm efficiencies are 67.2, 90.3 and 74.5 percent respectively, based on annual estimates for the years 1988-1997. Annual estimates are listed in Table 33. It is important to note that the estimate of on-farm efficiency is higher than the 70% figure reported by CVWD. This indicates that the groundwater contribution to CVWD irritation supply is higher than the 15% used in this report.

Waterusecomp8.xls

Table 33
Coachella Valley 1988 - 1997

	Units	Year 1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
1. Annual Cropped Acreage	Acres	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
2. Adjusted ETc	Ac-Ft/Ac	4.7	4.3	4.3	4.2	4.2	4.7	4.5	4.6	4.7	4.7	4.5
3. Average Leaching Requirement	%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%
4. Adjusted Unit Field Requirement	Ac-Ft/Ac	5.2	4.8	4.8	4.7	4.7	5.3	5.0	5.1	5.2	5.2	5.0
5. Adjusted Field Requirement	Ac-Ft/Yr	272,013	250,100	248,821	242,807	244,626	273,588	259,096	267,678	269,591	268,689	259,701
6. Effective Precipitation	Ac-Ft/Yr	12,713	4,479	2,798	13,691	23,596	18,039	7,139	15,060	20,012	6,856	12,438
7. Adjusted Net Irrigation Requirement, incl. LR.	Ac-Ft/Yr	259,301	245,621	246,023	229,116	221,031	255,550	251,957	252,618	249,579	261,832	247,263
8. Net Supply (mile post 0.2 off AAC)	Ac-Ft/Yr	324,712	347,269	356,609	307,607	294,594	304,172	316,057	313,018	322,335	318,053	320,443
9. Estimated GW Supply to ID #1	Ac-Ft/Yr	48,707	52,090	53,491	46,141	44,189	45,626	47,409	46,953	48,350	47,708	48,066
10. Total Water Supply to ID #1	Ac-Ft/Yr	373,419	399,359	410,100	353,748	338,783	349,798	363,466	359,971	370,685	365,761	368,509
11. Farm Headgate Delivery (Colo R. Water only)	Ac-Ft/Yr	283,341	303,593	311,491	271,761	258,627	272,474	289,548	284,401	289,521	280,569	284,533
12. Total Farm Headgate Delivery (SW & GW)	Ac-Ft/Yr	332,048	355,683	364,982	317,902	302,816	318,100	336,957	331,354	337,871	328,277	332,599
13. Estimated Overall Efficiency w/ LR	%	69.44%	61.50%	59.99%	64.77%	65.24%	73.06%	69.32%	70.18%	67.33%	71.59%	67.24%
14. Estimated On-Farm Efficiency w/LR	%	78.09%	69.06%	67.41%	72.07%	72.99%	80.34%	74.77%	76.24%	73.87%	79.76%	74.46%
15. Conv.& Dist. Efficiency (mile post 0.2)	%	88.92%	89.06%	89.00%	89.87%	89.38%	90.94%	92.71%	92.05%	91.15%	89.75%	90.28%

Notes:

1. Annual cropped acreage based on Boyle report estimate for 1987.
2. Adjusted ETc, calculated using Penman Monteith method, an adjusted number representing a reduction from potential ETc and addition to compensate for evaporation during pre-irrigation (about 2.5 " per crop).
3. Leaching requirement calculated using Rhoades method except for crops irrigated using high frequency drip and sprinkler irrigation methods.
4. Adjusted Unit Field Requirement, includes leaching fraction.
5. Adjusted Field Requirement, including leaching fraction.
6. Effective Precipitation based on SCS method.
7. Ajusted Net Irrigation Requirement = Adjusted ETc + Leaching Requirement - Effective Precipitation.
8. Net Supply at Coachella Canal at mile post 0.20 (Scott Coleson CVWD via USBR Yuma) from Compilation of Records in Accordance with Article V., U.S. Bureau of Reclamation 1988-1997.
9. Estimated GW Supply to ID #1 is based on CVWD estimate of 15%. Coachella Valley Water Problem: Severe Groundwater Overdraft "Possible Strategies and Opportunities: 1997 CVWD.
10. Sum of 2 and 3 above.
11. Farm Headgate Delivery (Colorado River Water only) Bureau of Reclamation Crop Production and Water Utilization Data reports 1988-1997.
12. Total Farm Headgate Delivery (SW & GW) Total of 3 and 5 above.
13. Estimated Overall Efficiency with Leaching Requirement is calculated as **Net Irrigation Requirement, including LR/Total Water Supply to ID #1.**
14. Estimated On-Farm Efficiency with Leaching Requirement is calculated as the **Net Irrigation Requirement, including LR/ Total Farm Headgate Delivery** (SW & GW).
15. Conveyance and Distribution Efficiency is calculated as **(13 Overall Efficiency)/(14 On-Farm Efficiency).**

Updated table

CONCLUSION

NRCE's determination of overall, conveyance/distribution, and on-farm efficiencies for IID are based on the water balance presented in the March 2002 report by NRCE. These efficiency estimates are 74.5, 89.4 and 83.4 percent respectively. Reference crop evapotranspiration from the various stations is expected to be relatively close from location to location, with some variation being represented by a decrease in ET_o as one travels east and up the Colorado River. One can see relatively close agreement between the CIMIS station representing IID and the one representing CVWD, however, a like agreement cannot be seen between the Palo Verde station at Palo Verde, California and the CRIR station at Parker, Arizona, which are near each other. There is indeed a difference in the computed ET_o between the two stations, which indicates a difference in the manner that CIMIS and AZMET stations collect, process, and use climate data for evapotranspiration calculations.

Soils within the districts along the Colorado River as well as CVWD predominantly reflect the formative processes associated with floodplains and the adjacent terraces. These soils are mostly coarser soils and except for high water tables are not drainage impacted. WMID has however in the past been impacted by accumulations of saline shallow groundwater resulting from local irrigation drainage. CVWD soils are generally high in permeability and have been formed from depositions associated with alluvial fans and some valley fill. Soils of IID are primarily lake bed soils with some wind and alluvial depositon and reworking. The majority of irrigated soils in IID are low permeability soils with high shrink-swell clays that form significant cracking upon drying.

Irrigation efficiency figures estimated for CVWD are based on an estimated groundwater contribution to irrigation water supply. The actual number is not known, but by using a groundwater contribution of 15% of surface water to arrive at total irrigation water supply yields an on-farm efficiency of 74.5%. This number is higher than the 70% figure reported by CVWD and indicates that more groundwater is used than initially estimated. Because of this it is reasonable to conclude that total irrigation water supply is greater and on-farm efficiency is in fact lower. Others have estimated CVWD on-farm efficiency to range from 57 to 70%. Boyle (1993) estimated on-farm efficiency to be 57% in the year 1987. An estimated on-farm efficiency of 70% was reported by CVWD in their 2002 Water Management Plan.

Based on the foregoing information, it can be said:

- IID has relatively good irrigation efficiencies.
- Water quality available to IID is lower in quality than for other districts.
- Soil conditions within IID are vastly different due to their lacustrine origin, which has resulted in soils of low permeability.
- Irrigated lands within IID tend to be under-irrigated and under leached.
- That drainage water from irrigation districts, other than IID, exist but are not visible, due to the relatively high permeability of soils found in those districts.
- That though IID is at the tail end of the Lower Colorado River System, its drainage water can be claimed and used for other purposes by other water users so inclined.
- IID's surface irrigation practices have been developed and used which are consistent with the conditions and crops grown there.

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Attachment 1

Arizona Meteorological Network. (1989-1997). AZMET Reference Crop Data.

IID Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		71	104	165	179	277	278	274	250	203	158	110	87
*Alfalfa - winter		65	0	0	0	0	0	0	0	0	39	116	93
*Alfalfa	32.02%	0	87	168	181	280	282	278	254	206	78	0	0
Wheat	12.96%	65	122	200	213	185	0	0	0	0	0	0	40
Sudan	11.61%	0	0	0	0	128	244	267	244	197	0	0	0
Sugar Beets	6.98%	87	127	202	211	274	144	0	0	35	121	104	101
Lettuce Late and Early	4.42%	73	71	0	0	0	0	0	0	0	72	115	90
Cantaloupes - Spring	3.00%	17	60	139	162	237	75	0	0	0	0	0	0
Cantaloupes - Fall													
*Bermuda, spring (seed)	2.90%	0	0	47	155	263	202	0	0	0	0	0	0
Carrots	2.73%	76	111	175	67	0	0	0	0	0	58	93	88
*Bermuda, summer hay	2.52%	0	0	0	0	0	86	275	262	211	136	0	0
Onions	2.03%	77	112	179	190	254	6	0	0	0	48	98	90
Average	18.83%	66	99	159	168	232	148	273	253	162	79	105	84
	100.00%												

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
Alfalfa and Winter Alfalfa	21	28	54	58	90	90	89	81	66	37	37	30
Wheat	8	16	26	28	24	0	0	0	0	0	0	5
Sudan	0	0	0	0	15	28	31	28	23	0	0	0
Sugar Beets	6	9	14	15	19	10	0	0	2	8	7	7
Lettuce Late and Early	3	3	0	0	0	0	0	0	0	3	5	4
Cantaloupes - Spring	1	2	4	5	7	2	0	0	0	0	0	0
Cantaloupes - Fall												
*Bermuda, spring (seed)	0	0	1	5	8	6	0	0	0	0	0	0
Carrots	2	3	5	2	0	0	0	0	0	2	3	2
*Bermuda, summer hay	0	0	0	0	0	2	7	7	5	3	0	0
Onions	2	2	4	4	5	0	0	0	0	1	2	2
Average	12	19	30	32	44	28	51	48	31	15	20	16
Sum (mm)	55	82	138	147	211	167	178	164	127	70	74	66
Sum (in)	2.16	3.21	5.42	5.79	8.32	6.58	7.02	6.45	5.00	2.74	2.91	2.60

Annual Totals IID	Year	Inches	Feet
	1988	58.2	4.85
	1989	60.7	5.06
	1990	56.4	4.70
	1991	47.9	3.99
	1992	48.0	4.00
	1993	53.1	4.43
	1994	54.5	4.54
	1995	55.7	4.64
	1996	59.2	4.93
	1997	55.4	4.61
		54.9	4.6

CRIR Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
Arizona Portion		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop (Az.)	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		81	110	165	195	287	293	314	242	214	165	108	91
*Alfalfa_winter		68	0	0	0	0	0	0	0	0	37	108	79
*Alfalfa	52.05%	0	93	187	198	290	297	318	246	217	82	0	0
Cotton (upland and PIMA)	31.19%	0	2	65	77	184	266	357	283	207	62	0	0
Wheat	6.87%	75	130	223	233	192	0	0	0	0	0	0	39
Sudan	2.21%	0	0	0	0	133	257	306	236	208	0	0	0
Cantaloupes - Spring	1.54%	23	64	155	177	246	76	0	0	0	0	0	0
Cantaloupes - Fall													
*Bermuda, spring (seed)	0.94%	0	0	50	169	273	214	0	0	0	0	0	0
Honeydew	0.74%	11	78	165	206	304	256	0	0	0	0	0	0
Onions	0.70%	88	119	199	208	263	6	0	0	0	50	95	94
*Bermuda, summer hay	0.57%	0	0	0	0	0	92	315	254	223	144	0	0
Oats and Barley	0.57%	86	130	218	149	13	0	0	0	0	0	15	39
Average	2.62%	59	88	158	177	211	183	324	255	214	75	73	63
	100.00%												

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
*Alfalfa and Winter Alfalfa	36	48	97	103	151	154	166	128	113	62	56	41
Cotton (upland and PIMA)	0	0	20	24	57	83	111	88	65	19	0	0
Wheat	5	9	15	16	13	0	0	0	0	0	0	3
Sudan	0	0	0	0	3	6	7	5	5	0	0	0
Cantaloupes - Spring	0	1	2	3	4	1	0	0	0	0	0	0
Cantaloupes - Fall	0	0	0	0	0	0	0	0	0	0	0	0
*Bermuda, spring (seed)	0	0	0	2	3	2	0	0	0	0	0	0
Honeydew	0	1	1	2	2	2	0	0	0	0	0	0
Onions	1	1	1	1	2	0	0	0	0	0	1	1
*Bermuda, summer hay	0	0	0	0	0	1	2	1	1	1	0	0
Oats and Barley	0	1	1	1	0	0	0	0	0	0	0	0
Average	2	2	4	5	6	5	8	7	6	2	2	2
Sum (mm)	44	63	144	156	241	253	294	230	189	84	59	46
Sum (In)	1.72	2.48	5.66	6.13	9.48	9.98	11.58	9.04	7.44	3.32	2.32	1.83

Annual Totals CRIR (Az.)	Year	Inches	Feet
	1988	71.0	5.92
	1989	77.5	6.46
	1990	70.9	5.91
	1991	71.2	5.93
	1992	72.6	6.05
	1993	77.2	6.43
	1994	80.4	6.70
	1995	84.8	7.07
	1996	85.6	7.14
	1997	81.2	6.76
		77.2	6.4

PVID Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop PVID	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		58	81	141	151	201	197	243	182	159	111	72	55
*Alfalfa - winter	incl	61	74	0	0	0	0	0	0	0	27	76	59
*Alfalfa	49.35%	0	68	143	153	203	200	246	184	161	54	0	0
Cotton (upland and PIMA)	14.30%	0	1	49	60	128	179	276	213	152	41	0	0
Wheat	7.40%	53	95	171	181	135	0	0	0	0	0	0	23
Sudan	5.26%	0	0	0	0	91	173	237	177	154	0	0	0
*Perm. Pasture + Misc.	4.15%	0	0	73	140	200	197	243	182	158	90	0	0
Cantaloupes - Spring	3.68%	17	47	118	137	172	52	0	0	0	0	0	0
Lettuce Late and Early	3.66%	59	55	0	0	0	0	0	0	0	51	75	57
*Citrus	1.59%	40	56	99	106	143	143	180	135	118	83	54	42
Oats and Barley	1.41%	61	95	166	114	9	0	0	0	0	0	10	24
*Bermuda, summer hay	1.37%	0	0	0	0	0	62	246	191	166	96	0	0
Average	7.83%	48	61	117	127	135	144	238	181	151	63	54	41
	100.00%												

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
Alfalfa and Winter Alfalfa	30	70	71	76	100	99	121	91	79	40	37	29
Cotton (upland and PIMA)	0	0	7	9	18	26	40	30	22	6	0	0
Sudan	4	7	13	13	10	0	0	0	0	0	0	2
Wheat	0	0	0	0	5	9	12	9	8	0	0	0
*Perm. Pasture + Misc.	0	0	3	6	8	8	10	8	7	4	0	0
Cantaloupes - Spring	1	2	4	5	6	2	0	0	0	0	0	0
Oats and Barley	2	2	0	0	0	0	0	0	0	2	3	2
*Citrus	1	1	2	2	2	2	3	2	2	1	1	1
Lettuce Late and Early	1	1	2	2	0	0	0	0	0	0	0	0
Average	4	5	9	10	11	11	19	14	12	5	4	3
Sum (mm)	42	88	111	122	161	157	205	155	129	58	45	37
Sum (In)	1.66	3.47	4.36	4.79	6.35	6.17	8.07	6.09	5.09	2.28	1.79	1.46

Annual Totals PVID	Year	Inches	Feet
	1988	51.6	4.30
	1989	51.5	4.29
	1990	58.4	4.86
	1991	55.5	4.62
	1992	59.8	4.98
	1993	62.6	5.22
	1994	67.3	5.60
	1995	60.5	5.04
	1996	59.0	4.92
	1997	53.3	4.44
			4.8

WMID Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop WMID	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		98	142	193	181	242	252	265	245	234	160	105	92
***Alfalfa_winter**	incl	66	0	0	0	0	0	0	0	0	39	116	93
***Alfalfa**	22.94%	0	118	195	183	246	256	269	248	237	83	0	0
Lettuce Late and Early	22.13%	100	102	0	0	0	0	0	0	0	67	109	94
Cotton (upland and PIMA)	18.14%	0	2	67	71	154	230	301	286	226	64	0	0
Wheat	16.33%	90	167	233	216	166	0	0	0	0	0	0	37
Other Hay (use alfalfa)	6.84%												
Alfalfa_Seed	5.06%	0	118	195	183	246	165	153	120	0	0	0	0
***Citrus**	1.74%	69	99	135	127	173	183	196	182	174	119	78	69
***Peach Trees**	0.93%	54	78	133	158	242	253	266	246	235	161	104	77
Cauliflower	0.85%	104	22	0	0	0	0	0	0	22	112	87	95
***Misc. Field Crops**	0.78%	12	75	230	227	151	0	0	0	0	0	0	0
Average	4.26%	71	87	170	166	197	217	237	216	179	92	99	77

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
Alfalfa	15.1	27.0	44.8	42.0	56.3	58.6	61.6	56.9	54.3	27.9	26.7	21.3
Lettuce	22.1	22.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.8	24.0	20.9
Cotton	0.0	0.4	12.2	12.9	28.0	41.7	54.7	51.9	41.0	11.5	0.0	0.0
Wheat	14.7	27.2	38.1	35.2	27.1	0.0	0.0	0.0	0.0	0.0	0.0	6.0
Other Hay (use alfalfa)	4.5	8.1	13.4	12.5	16.8	17.5	18.4	17.0	16.2	8.3	8.0	6.4
Seed (assumed alfalfa seed)	0.0	6.0	9.9	9.3	12.4	8.4	7.8	6.1	0.0	0.0	0.0	0.0
Citrus	1.2	1.7	2.3	2.2	3.0	3.2	3.4	3.2	3.0	2.1	1.4	1.2
Nuts (used peach trees)	0.5	0.7	1.2	1.5	2.3	2.4	2.5	2.3	2.2	1.5	1.0	0.7
Cauliflower	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.0	0.7	0.8
Other Field	0.1	0.6	1.8	1.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	3.0	3.7	7.2	7.1	8.4	9.3	10.1	9.2	7.6	3.9	4.2	3.3
Sum (mm)	62.1	98.2	131.0	124.5	155.4	141.0	158.5	146.4	124.6	71.1	66.0	60.6
Sum (in)	2.4	3.9	5.2	4.9	6.1	5.5	6.2	5.8	4.9	2.8	2.6	2.4

Annual Totals WMID	**Year**	**Inches**	**Feet**
	1988	52.7	4.39
	1989	56.8	4.74
	1990	55.1	4.60
	1991	52.3	4.36
	1992	53.3	4.44
	1993	57.6	4.80
	1994	55.8	4.65
	1995	55.8	4.65
	1996	55.5	4.63
	1997	52.5	4.37
		54.8	4.6

CVWD Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop CVWD	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		74	111	172	194	277	289	275	262	227	148	96	79
Citrus	22.32%	52	77	120	136	198	211	204	195	169	110	72	59
Grapes	21.18%	26	49	107	151	225	232	203	171	128	72	38	25
Dates	8.85%	93	138	215	246	372	405	385	367	311	198	125	100
Corn	7.21%	0	78	187	241	320	0	0	0	0	0	0	0
Lettuce Late and Early	4.66%	76	79	0	0	0	0	0	0	0	61	100	81
Other Veg (Lettuce)	4.53%	76	79	0	0	0	0	0	0	0	61	100	81
Alfalfa	3.05%	0	91	174	197	281	293	279	266	230	78	0	0
Alfalfa_winter	incl	62	0	0	0	0	0	0	0	0	34	101	85
Sudan	2.69%	0	0	0	0	123	255	268	256	220	0	0	0
Broccoli	2.61%	78	70	0	0	0	0	0	0	0	83	73	77
Carrots	2.51%	79	118	182	73	0	0	0	0	0	49	80	80
Average	20.40%	68	87	164	174	253	279	268	251	212	83	86	74
	100.00%												

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
Citrus	11.6	17.3	26.9	30.4	44.1	47.0	45.5	43.6	37.7	24.7	16.0	13.3
Grapes	5.5	10.3	22.6	32.0	47.6	49.2	42.9	36.2	27.1	15.2	8.0	5.3
Dates	8.2	12.2	19.0	21.8	33.0	35.8	34.1	32.4	27.5	17.5	11.0	8.9
Corn	0.0	5.6	13.5	17.4	23.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lettuce	3.5	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	4.6	3.8
Other Veg (Lettuce)	3.4	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	4.5	3.7
Alfalfa	1.9	2.8	5.3	6.0	8.6	8.9	8.5	8.1	7.0	3.4	3.1	2.6
Sudan	0.0	0.0	0.0	0.0	3.3	6.9	7.2	6.9	5.9	0.0	0.0	0.0
Broccoli	2.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.9	2.0
Carrots	2.0	3.0	4.6	1.8	0.0	0.0	0.0	0.0	0.0	1.2	2.0	2.0
Average	13.8	17.6	33.6	35.5	51.7	56.9	54.6	51.2	43.2	16.9	17.5	15.0
Sum (mm)	51.9	77.8	125.5	144.8	211.3	204.8	192.7	178.4	148.5	86.7	68.7	56.5
Sum (in)	2.0	3.1	4.9	5.7	8.3	8.1	7.6	7.0	5.8	3.4	2.7	2.2

Annual Totals CVWD	Year	Inches	Feet
	1988	60.9	5.08
	1989	55.9	4.66
	1990	55.6	4.64
	1991	54.2	4.52
	1992	54.7	4.56
	1993	61.3	5.11
	1994	58.0	4.83
	1995	59.9	4.99
	1996	60.4	5.03
	1997	60.2	5.01
		58.1	4.8

Attachment 2

Bower, C. A. (1989). "Reasonable Water Requirements for Irrigation, IID and CVWD: Salinity Control and Irrigation Efficiency Aspects."

REASONABLE WATER REQUIREMENTS FOR IRRIGATION, IID AND CVWD: SALINITY CONTROL AND IRRIGATION EFFICIENCY ASPECTS.

C.A. Bower

The objective of this study covering the period 1971-1981, inclusive, was to fulfill part of a larger objective stated by Harvey O. Banks in an October 10, 1988 communication as follows: "to estimate the reasonable annual amounts of water required by CVWD and by IID to satisfy the irrigation requirements for the irrigated lands within each district under conditions of reasonable use of water, reasonable methods of use and reasonable methods of diversion, as required by Article X, Section 2, of the State Constitution". Leach water for salinity control, rootzone and district salt balances, and irrigation efficiency are considered in the present study.

Leach Water for Salinity Control

The commonly used US Salinity Laboratory concept of leaching requirement (13)* is defined as the fraction of irrigation water entering the soil that over time must pass through the rootzone to control soil salinity at a specified level. It assumes that soil permeability and drainage conditions permit the specified leaching, and that precipitation of salts in the soil, dissolution of soil minerals and removal of salt in the harvested crop are either negligible or counterbalancing. Under these conditions the requirement depends only on the salt concentration of the irrigation water and the salt tolerance of the crop. In practice, the fraction is obtained by dividing the salt concentration of the irrigation water by the salt concentration of the soil saturation extract associated with a 50% yield reduction** of the crop, the method having been validated by Bower et al. (2) with cropped outdoor lysimeters. Data relating the relative yield of most crops to the salt concentration of the soil saturation extract have been given by Maas and Hoffman (7)

While the climate and imported irrigation water are essentially the same for the IID and CVWD, the soils of the districts are markedly different. The soils of the IID consist of highly stratified, predominantly clay and silt Colorado River deposits (9) whereas the CVWD soils consist of coarse sediments having thin irregular strata of clays and silts washed out from nearby mountains (5). According to Haddah and Rhoades (4) 59% of IID soils have a texture of clay, silty clay or clay loam throughout the infiltration control section (10"-40" depth); 25% have a clay or silty clay texture in either the upper or lower portion of the control section; and 14% are silt or fine sandy loams throughout. Except for a few percent of clay loam soils near the Salton Sea all CVWD soils are sandy loams or loamy sands

+ Underlined numbers in parentheses refer to Literature Cited
++See footnote on page 2.

Attachment 3

Boyle Engineering Corporation (1993). "On-farm Irrigation Efficiency." Special Technical Report for Coachella Valley Water District.

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ON-FARM

IRRIGATION EFFICIENCY

SPECIAL TECHNICAL REPORT

COACHELLA VALLEY WATER DISTRICT

REGISTERED PROFESSIONAL ENGINEER
STUART W. STYLES
No. 44965
Exp. 3/31/94
CIVIL
STATE OF CALIFORNIA

Stuart Styles, PE
Project Manager

APRIL 1993

Attachment 4

Boyle Engineering Corporation. (1993). "On-farm Irrigation Efficiency." Special Technical Report for Imperial Irrigation District.

ON-FARM
IRRIGATION EFFICIENCY

SPECIAL TECHNICAL REPORT

FOR

IMPERIAL IRRIGATION DISTRICT

Stuart Styles

REGISTERED PROFESSIONAL ENGINEER
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TABLE OF CONTENTS

Attachment 5

Boyle Engineering Corporation (1990). "Tailwater Recovery: Demonstration Program Study". Special Technical Report to Imperial Irrigation District.

TAILWATER RECOVERY

DEMONSTRATION PROGRAM STUDY

SPECIAL TECHNICAL REPORT

SEPTEMBER 1990

IMPERIAL IRRIGATION DISTRICT
CALIFORNIA

IMPERIAL IRRIGATION DISTRICT
AVERAGE SOIL SALINITY ACROSS SELECTED LOCATIONS - PUMPBACK SYSTEM #1

NORTHWEST - SITE 1

DEPTH (in.)	EC SUMMER 1985	EC SUMMER 1988	'85 TO '88 PERCENT INCREASE	EC WINTER 1990	'88 TO '90 PERCENT INCREASE
6	4.7	3.1	-34%	2.2	-29%
12	6.5	3.3	-49%	3.4	3%
24	9.0	4.2	-53%	4.6	10%
36	9.9	4.2	-58%	5.7	36%
48	9.5	4.6	-52%	5.3	15%
60	9.4	4.5	-52%	5.6	24%
AVG	8.2	4.0	-51%	4.5	12%

NORTHEAST - SITE 1

DEPTH (in.)	EC SUMMER 1985	EC SUMMER 1988	'85 TO '88 PERCENT INCREASE	EC WINTER 1990	'88 TO '90 PERCENT INCREASE
6	2.9	1.9	-34%	1.6	-16%
12	4.2	2.5	-40%	2.1	-16%
24	5.8	2.5	-57%	3.1	24%
36	6.6	3.7	-44%	4.6	24%
48	8.1	3.5	-57%	4.1	17%
60	7.5	4.1	-45%	5.4	32%
AVG	5.9	3.0	-48%	3.5	15%

SOUTHWEST - SITE 1

DEPTH (in.)	EC SUMMER 1985	EC SUMMER 1988	'85 TO '88 PERCENT INCREASE	EC WINTER 1990	'88 TO '90 PERCENT INCREASE
6	3.1	1.2	-61%	1.7	42%
12	3.5	1.2	-66%	2.1	75%
24	3.8	1.5	-61%	2.4	60%
36	3.7	2.4	-35%	4.9	104%
48	5.3	3.2	-40%	5.1	59%
60	5.8	3.3	-43%	5.7	73%
AVG	4.2	2.1	-49%	3.7	71%

SOUTHEAST - SITE 1

DEPTH (in.)	EC SUMMER 1985	EC SUMMER 1988	'85 TO '88 PERCENT INCREASE	EC WINTER 1990	'88 TO '90 PERCENT INCREASE
6	1.7	1.3	-24%	1.8	38%
12	1.7	1.4	-18%	1.9	36%
24	3.3	2.2	-33%	2.3	5%
36	4.3	3.2	-26%	4.1	28%
48	5.5	3.6	-35%	5.0	39%
60	4.1	3.2	-22%	4.6	44%
AVG	3.4	2.5	-28%	3.3	32%

AVERAGE ELECTRICAL CONDUCTIVITY 1985 TO 1988 PERCENT INCREASE FOR SITE 1 = -46%
AVERAGE ELECTRICAL CONDUCTIVITY 1988 TO 1990 PERCENT INCREASE FOR SITE 1 = 28%
AVERAGE ELECTRICAL CONDUCTIVITY 1985 TO 1990 PERCENT INCREASE FOR SITE 1 = -31%

NOTE: NEGATIVE VALUES SIGNIFY DECREASES IN THE AVERAGE SOIL SALINITY.
ECe VALUES (MMHOS/CM) AVERAGED FROM SAMPLES OVER TILE DRAINS.

Attachment 6

Burt, C. M. (1990). "Efficiency in Irrigation." California Polytechnic State University, San Luis Obispo, California.

EFFICIENCY IN IRRIGATION

by

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October 1990

EFFICIENCY IN IRRIGATION

by

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General Discussion of Irrigation Efficiency

Introduction to California Irrigation

Agricultural irrigation plays a major role in water and power consumption in California. Over 30 million acre-feet (30 MAF) of water are used per year for agricultural irrigation (Hagan and Davenport, 1981). This represents 85% of the diverted or pumped water in the state.

Electricity powers over 90% of the agricultural pumps in California (Calif. DWR, 1984). Approximately 5 billion kilowatt hours of electricity are used annually for pumping (Kah, et. al, 1983). These figures do not include the pumping requirements of the many irrigation districts or Federal and State canal systems, such as the California Aqueduct.

California has a large diversity of agricultural irrigation systems, covering over 10 million acres. Virtually every viable method of irrigation used in the world can be found in California. Of the total acreage, 70% is covered by "surface" irrigation methods (furrow, border strip, rice, and basin) (Irrigation Journal, 1989). The other 30% is irrigated by pressurized methods (drip and sprinkler). Pressurized irrigated acreage has almost doubled in the last 10 years in California, although total irrigated acreage has slightly dropped since 1984.

Controversy and Confusion

A study by the GAO (1976) in 1976 found that the average on-farm irrigation efficiency in the U.S. is 50%. At first glance, this would appear to mean that twice as many acres could be farmed if the irrigation efficiency was improved to 100%. However, studies in California have indicated that achievable water

Attachment 7

California Irrigation Management Information Systems. (1989-1997). CIMIS Reference Crop Data.

IID Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		71	104	165	179	277	278	274	250	203	158	110	87
*Alfalfa - winter		65	0	0	0	0	0	0	0	0	39	116	93
*Alfalfa	32.02%	0	87	168	181	280	282	278	254	206	78	0	0
Wheat	12.96%	65	122	200	213	185	0	0	0	0	0	0	40
Sudan	11.61%	0	0	0	0	128	244	267	244	197	0	0	0
Sugar Beets	6.98%	87	127	202	211	274	144	0	0	35	121	104	101
Lettuce Late and Early	4.42%	73	71	0	0	0	0	0	0	0	72	115	90
Cantaloupes - Spring	3.00%	17	60	139	162	237	75	0	0	0	0	0	0
Cantaloupes - Fall													
*Bermuda, spring (seed)	2.90%	0	0	47	155	263	202	0	0	0	0	0	0
Carrots	2.73%	76	111	175	67	0	0	0	0	0	58	93	88
*Bermuda, summer hay	2.52%	0	0	0	0	0	86	275	262	211	136	0	0
Onions	2.03%	77	112	179	190	254	6	0	0	0	48	98	90
Average	18.83%	66	99	159	168	232	148	273	253	162	79	105	84
	100.00%												

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
Alfalfa and Winter Alfalfa	21	28	54	58	90	90	89	81	66	37	37	30
Wheat	8	16	26	28	24	0	0	0	0	0	0	5
Sudan	0	0	0	0	15	28	31	28	23	0	0	0
Sugar Beets	6	9	14	15	19	10	0	0	2	8	7	7
Lettuce Late and Early	3	3	0	0	0	0	0	0	0	3	5	4
Cantaloupes - Spring	1	2	4	5	7	2	0	0	0	0	0	0
Cantaloupes - Fall												
*Bermuda, spring (seed)	0	0	1	5	8	6	0	0	0	0	0	0
Carrots	2	3	5	2	0	0	0	0	0	2	3	2
*Bermuda, summer hay	0	0	0	0	0	2	7	7	5	3	0	0
Onions	2	2	4	4	5	0	0	0	0	1	2	2
Average	12	19	30	32	44	28	51	48	31	15	20	16
Sum (mm)	55	82	138	147	211	167	178	164	127	70	74	66
Sum (in)	2.16	3.21	5.42	5.79	8.32	6.58	7.02	6.45	5.00	2.74	2.91	2.60

Annual Totals IID	Year	Inches	Feet
	1988	58.2	4.85
	1989	60.7	5.06
	1990	56.4	4.70
	1991	47.9	3.99
	1992	48.0	4.00
	1993	53.1	4.43
	1994	54.5	4.54
	1995	55.7	4.64
	1996	59.2	4.93
	1997	55.4	4.61
		54.9	4.6

IID Monthly ETc (mm)		13	14	15	16	17	18	19	20	21	22	23	24
		434	463	495	526	558	589	621	653	684	716	747	779
		31	28	31	30	31	30	31	31	30	31	30	31
Crop	% Dist	Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
ETo		74	96	163	209	280	312	307	264	225	160	98	68
*Alfalfa - winter		63	0	0	0	0	0	0	0	0	41	103	72
*Alfalfa	32.02%	0	79	165	212	284	316	311	267	228	83	0	0
Wheat	12.96%	68	112	197	251	194	0	0	0	0	0	0	32
Sudan	11.61%	0	0	0	0	126	275	299	257	218	0	0	0
Sugar Beets	6.98%	90	117	200	248	280	167	0	0	44	123	92	78
Lettuce Late and Early	4.42%	75	64	0	0	0	0	0	0	0	75	101	70
Cantaloupes - Spring	3.00%	30	61	142	189	228	26	0	0	0	0	0	0
Cantaloupes - Fall													
*Bermuda, spring (seed)	2.90%	0	0	40	182	266	223	0	0	0	0	0	0
Carrots	2.73%	79	102	173	82	0	0	0	0	0	61	82	69
*Bermuda, summer hay	2.52%	0	0	0	0	0	103	309	276	234	138	0	0
Onions	2.03%	80	103	176	223	259	14	0	0	0	53	87	70
Average	18.83%	69	91	156	198	234	161	307	267	181	82	93	65
	100.00%												

Weighting Factors	Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
Alfalfa and Winter Alfalfa	20	25	53	68	91	101	100	86	73	40	33	23
Wheat	9	15	26	33	25	0	0	0	0	0	0	4
Sudan	0	0	0	0	15	32	35	30	25	0	0	0
Sugar Beets	6	8	14	17	20	12	0	0	3	9	6	5
Lettuce Late and Early	3	3	0	0	0	0	0	0	0	3	4	3
Cantaloupes - Spring	1	2	4	6	7	1	0	0	0	0	0	0
Cantaloupes - Fall												
*Bermuda, spring (seed)	0	0	1	5	8	6	0	0	0	0	0	0
Carrots	2	3	5	2	0	0	0	0	0	2	2	2
*Bermuda, summer hay	0	0	0	0	0	3	8	7	6	3	0	0
Onions	2	2	4	5	5	0	0	0	0	1	2	1
Average	13	17	29	37	44	30	58	50	34	15	18	12
Sum (mm)	56	75	136	173	214	185	200	173	141	73	65	52
Sum (in)	2.22	2.94	5.34	6.80	8.43	7.29	7.87	6.80	5.56	2.88	2.57	2.03

Annual Totals IID

CRIR Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
Arizona Portion		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop (Az.)	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		81	110	185	195	287	293	314	242	214	165	108	91
*Alfalfa_winter		68	0	0	0	0	0	0	0	0	37	108	79
*Alfalfa	52.05%	0	93	187	198	290	297	318	246	217	82	0	0
Cotton (upland and PIMA)	31.19%	0	2	65	77	184	266	357	283	207	62	0	0
Wheat	6.87%	75	130	223	233	192	0	0	0	0	0	0	39
Sudan	2.21%	0	0	0	0	133	257	306	236	208	0	0	0
Cantaloupes - Spring	1.54%	23	64	155	177	246	76	0	0	0	0	0	0
Cantaloupes - Fall													
*Bermuda, spring (seed)	0.94%	0	0	50	169	273	214	0	0	0	0	0	0
Honeydew	0.74%	11	78	165	206	304	256	0	0	0	0	0	0
Onions	0.70%	88	119	199	208	263	6	0	0	0	50	95	94
*Bermuda, summer hay	0.57%	0	0	0	0	0	92	315	254	223	144	0	0
Oats and Barley	0.57%	86	130	218	149	13	0	0	0	0	0	15	39
Average	2.62%	59	88	158	177	211	183	324	255	214	75	73	63
	100.00%												

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
*Alfalfa and Winter Alfalfa	36	48	97	103	151	154	166	128	113	62	56	41
Cotton (upland and PIMA)	0	0	20	24	57	83	111	88	65	19	0	0
Wheat	5	9	15	16	13	0	0	0	0	0	0	3
Sudan	0	0	0	0	3	6	7	5	5	0	0	0
Cantaloupes - Spring	0	1	2	3	4	1	0	0	0	0	0	0
Cantaloupes - Fall	0	0	0	0	0	0	0	0	0	0	0	0
*Bermuda, spring (seed)	0	0	0	2	3	2	0	0	0	0	0	0
Honeydew	0	1	1	2	2	2	0	0	0	0	0	0
Onions	1	1	1	1	2	0	0	0	0	0	1	1
*Bermuda, summer hay	0	0	0	0	0	1	2	1	1	1	0	0
Oats and Barley	0	1	1	1	0	0	0	0	0	0	0	0
Average	2	2	4	5	6	5	8	7	6	2	2	2
Sum (mm)	44	63	144	156	241	253	294	230	189	84	59	46
Sum (in)	1.72	2.48	5.66	6.13	9.48	9.98	11.58	9.04	7.44	3.32	2.32	1.83

Annual Totals CRIR (Az.)	Year	Inches	Feet
	1988	71.0	5.92
	1989	77.5	6.46
	1990	70.9	5.91
	1991	71.2	5.93
	1992	72.6	6.05
	1993	77.2	6.43
	1994	80.4	6.70
	1995	84.8	7.07
	1996	85.6	7.14
	1997	81.2	6.76
		77.2	6.4

CRIR Monthly ETc (mm)		13	14	15	16	17	18	19	20	21	22	23	24
Arizona Portion		434	463	495	526	558	589	621	653	684	716	747	779
		31	28	31	30	31	30	31	31	30	31	30	31
Crop (Az.)	% Dist	Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
ETo		85	122	211	255	288	320	304	274	246	182	122	93
*Alfalfa_winter		87	0	0	0	0	0	0	0	0	36	106	89
*Alfalfa	52.05%	0	100	214	258	292	325	308	278	249	91	0	0
Cotton (upland and PIMA)	31.19%	0	0	74	97	182	289	344	320	241	70	0	0
Wheat	6.87%	78	142	255	306	202	0	0	0	0	0	0	43
Sudan	2.21%	0	0	0	0	124	283	296	267	238	0	0	0
Cantaloupes - Spring	1.54%	36	77	184	231	235	29	0	0	0	0	0	0
Cantaloupes - Fall													
*Bermuda, spring (seed)	0.94%	0	0	53	219	274	231	0	0	0	0	0	0
Honeydew	0.74%	9	86	185	269	306	287	0	0	0	0	0	0
Onions	0.70%	92	131	228	272	267	15	0	0	0	62	109	95
*Bermuda, summer hay	0.57%	0	0	0	0	0	105	305	287	256	155	0	0
Oats and Barley	0.57%	89	143	249	207	17	0	0	0	0	0	19	40
Average	2.62%	65	113	180	232	211	196	313	288	246	83	78	67
	100.00%												

Weighting Factors	Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
*Alfalfa and Winter Alfalfa	45	52	111	134	152	169	160	144	130	66	55	46
Cotton (upland and PIMA)	0	0	23	30	57	90	107	100	75	22	0	0
Wheat	5	10	18	21	14	0	0	0	0	0	0	3
Sudan	0	0	0	0	3	6	7	6	5	0	0	0
Cantaloupes - Spring	1	1	3	4	4	0	0	0	0	0	0	0
Cantaloupes - Fall	0	0	0	0	0	0	0	0	0	0	0	0
*Bermuda, spring (seed)	0	0	0	2	3	2	0	0	0	0	0	0
Honeydew	0	1	1	2	2	2	0	0	0	0	0	0
Onions	1	1	2	2	2	0	0	0	0	0	1	1
*Bermuda, summer hay	0	0	0	0	0	1	2	2	1	1	0	0
Oats and Barley	1	1	1	1	0	0	0	0	0	0	0	0
Average	2	3	5	6	6	5	8	8	6	2	2	2
Sum (mm)	54	69	164	202	241	276	284	259	218	91	58	52
Sum (in)	2.13	2.70	6.47	7.97	9.50	10.86	11.19	10.21	8.57	3.60	2.29	2.04

Annual Totals CRIR (Az.)

PVID Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop PVID	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		58	81	141	151	201	197	243	182	159	111	72	55
*Alfalfa - winter	incl	61	74	0	0	0	0	0	0	0	27	76	59
*Alfalfa	49.35%	0	68	143	153	203	200	246	184	161	54	0	0
Cotton (upland and PIMA)	14.30%	0	1	49	60	128	179	276	213	152	41	0	0
Wheat	7.40%	53	95	171	181	135	0	0	0	0	0	0	23
Sudan	5.26%	0	0	0	0	91	173	237	177	154	0	0	0
*Perm. Pasture + Misc.	4.15%	0	0	73	140	200	197	243	182	158	90	0	0
Cantaloupes - Spring	3.68%	17	47	118	137	172	52	0	0	0	0	0	0
Lettuce Late and Early	3.66%	59	55	0	0	0	0	0	0	0	51	75	57
*Citrus	1.59%	40	56	99	106	143	143	180	135	118	83	54	42
Oats and Barley	1.41%	61	95	166	114	9	0	0	0	0	0	10	24
*Bermuda, summer hay	1.37%	0	0	0	0	0	62	246	191	166	96	0	0
Average	7.83%	48	61	117	127	135	144	238	181	151	63	54	41
	100.00%												

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
Alfalfa and Winter Alfalfa	30	70	71	76	100	99	121	91	79	40	37	29
Cotton (upland and PIMA)	0	0	7	9	18	26	40	30	22	6	0	0
Sudan	4	7	13	13	10	0	0	0	0	0	0	2
Wheat	0	0	0	0	5	9	12	9	8	0	0	0
*Perm. Pasture + Misc.	0	0	3	6	8	8	10	8	7	4	0	0
Cantaloupes - Spring	1	2	4	5	6	2	0	0	0	0	0	0
Oats and Barley	2	2	0	0	0	0	0	0	0	2	3	2
*Citrus	1	1	2	2	2	2	3	2	2	1	1	1
Lettuce Late and Early	1	1	2	2	0	0	0	0	0	0	0	0
Average	4	5	9	10	11	11	19	14	12	5	4	3
Sum (mm)	42	88	111	122	161	157	205	155	129	58	45	37
Sum (in)	1.66	3.47	4.36	4.79	6.35	6.17	8.07	6.09	5.09	2.28	1.79	1.46

Annual Totals PVID	Year	Inches	Feet
	1988	51.6	4.30
	1989	51.5	4.29
	1990	58.4	4.86
	1991	55.5	4.62
	1992	59.8	4.98
	1993	62.6	5.22
	1994	67.3	5.60
	1995	60.5	5.04
	1996	59.0	4.92
	1997	53.3	4.44
			4.8

PVID Monthly ETc (mm)		13	14	15	16	17	18	19	20	21	22	23	24
		434	463	495	526	558	589	621	653	684	716	747	779
		31	28	31	30	31	30	31	31	30	31	30	31
Crop PVID	% Dist	Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
ETo		59	76	141	175	201	241	241	197	136	99	67	64
***Alfalfa - winter**	incl	52	0	0	0	0	0	0	0	0	29	71	68
***Alfalfa**	49.35%	0	63	143	178	204	245	244	199	138	46	0	0
Cotton (upland and PIMA)	14.30%	0	0	49	67	127	217	273	230	134	35	0	0
Wheat	7.40%	54	89	170	211	141	0	0	0	0	0	0	30
Sudan	5.26%	0	0	0	0	88	213	235	192	132	0	0	0
***Perm. Pasture + Misc.**	4.15%	0	0	72	162	201	241	241	196	135	78	0	0
Cantaloupes - Spring	3.68%	25	48	123	159	164	20	0	0	0	0	0	0
Lettuce Late and Early	3.66%	60	49	0	0	0	0	0	0	0	52	70	65
***Citrus**	1.59%	41	53	99	123	143	176	178	146	101	74	50	48
Oats and Barley	1.41%	62	90	166	140	12	0	0	0	0	0	10	28
***Bermuda, summer hay**	1.37%	0	0	0	0	0	78	243	207	142	83	0	0
Average	7.83%	49	66	117	148	135	170	236	195	130	57	50	48
	100.00%												

Weighting Factors	Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
Alfalfa and Winter Alfalfa	26	31	70	88	101	121	121	98	68	37	35	33
Cotton (upland and PIMA)	0	0	7	10	18	31	39	33	19	5	0	0
Sudan	4	7	13	16	10	0	0	0	0	0	0	2
Wheat	0	0	0	0	5	11	12	10	7	0	0	0
***Perm. Pasture + Misc.**	0	0	3	7	8	10	10	8	6	3	0	0
Cantaloupes - Spring	1	2	5	6	6	1	0	0	0	0	0	0
Oats and Barley	2	2	0	0	0	0	0	0	0	2	3	2
***Citrus**	1	1	2	2	2	3	3	2	2	1	1	1
Lettuce Late and Early	1	1	2	2	0	0	0	0	0	0	0	0
Average	4	5	9	12	11	13	18	15	10	4	4	4
Sum (mm)	38	48	111	141	161	190	203	167	112	53	42	43
Sum (in)	1.50	1.91	4.36	5.55	6.34	7.47	8.00	6.58	4.39	2.07	1.67	1.69

Annual Totals PVID

WMID Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop WMID	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		98	142	193	181	242	252	265	245	234	160	105	92
***Alfalfa_winter**	incl	66	0	0	0	0	0	0	0	0	39	116	93
***Alfalfa**	22.94%	0	118	195	183	246	256	269	248	237	83	0	0
Lettuce Late and Early	22.13%	100	102	0	0	0	0	0	0	0	67	109	94
Cotton (upland and PIMA)	18.14%	0	2	67	71	154	230	301	286	226	64	0	0
Wheat	16.33%	90	167	233	216	166	0	0	0	0	0	0	37
Other Hay (use alfalfa)	6.84%												
Alfalfa_Seed	5.06%	0	118	195	183	246	165	153	120	0	0	0	0
***Citrus**	1.74%	69	99	135	127	173	183	196	182	174	119	78	69
***Peach Trees**	0.93%	54	78	133	158	242	253	266	246	235	161	104	77
Cauliflower	0.85%	104	22	0	0	0	0	0	0	22	112	87	95
***Misc. Field Crops**	0.78%	12	75	230	227	151	0	0	0	0	0	0	0
Average	4.26%	71	87	170	166	197	217	237	216	179	92	99	77

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
Alfalfa	15.1	27.0	44.8	42.0	56.3	58.6	61.6	56.9	54.3	27.9	26.7	21.3
Lettuce	22.1	22.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.8	24.0	20.9
Cotton	0.0	0.4	12.2	12.9	28.0	41.7	54.7	51.9	41.0	11.5	0.0	0.0
Wheat	14.7	27.2	38.1	35.2	27.1	0.0	0.0	0.0	0.0	0.0	0.0	6.0
Other Hay (use alfalfa)	4.5	8.1	13.4	12.5	16.8	17.5	18.4	17.0	16.2	8.3	8.0	6.4
Seed (assumed alfalfa seed)	0.0	6.0	9.9	9.3	12.4	8.4	7.8	6.1	0.0	0.0	0.0	0.0
Citrus	1.2	1.7	2.3	2.2	3.0	3.2	3.4	3.2	3.0	2.1	1.4	1.2
Nuts (used peach trees)	0.5	0.7	1.2	1.5	2.3	2.4	2.5	2.3	2.2	1.5	1.0	0.7
Cauliflower	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.0	0.7	0.8
Other Field	0.1	0.6	1.8	1.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	3.0	3.7	7.2	7.1	8.4	9.3	10.1	9.2	7.6	3.9	4.2	3.3
Sum (mm)	62.1	98.2	131.0	124.5	155.4	141.0	158.5	146.4	124.6	71.1	66.0	60.6
Sum (in)	2.4	3.9	5.2	4.9	6.1	5.5	6.2	5.8	4.9	2.8	2.6	2.4

Annual Totals WMID	**Year**	**Inches**	**Feet**
	1988	52.7	4.39
	1989	56.8	4.74
	1990	55.1	4.60
	1991	52.3	4.36
	1992	53.3	4.44
	1993	57.6	4.80
	1994	55.8	4.65
	1995	55.8	4.65
	1996	55.5	4.63
	1997	52.5	4.37
		54.8	4.6

WMID Monthly ETc (mm)

Crop WMID	% Dist	Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
		13	14	15	16	17	18	19	20	21	22	23	24
		434	463	495	526	558	589	621	653	684	716	747	779
		31	28	31	30	31	30	31	31	30	31	30	31
ETo		101	112	181	227	269	296	317	263	242	185	130	108
***Alfalfa_winter**	incl	63	0	0	0	0	0	0	0	0	41	103	72
***Alfalfa**	22.94%	0	93	183	230	273	300	321	267	245	89	0	0
Lettuce Late and Early	22.13%	103	71	0	0	0	0	0	0	0	94	135	111
Cotton (upland and PIMA)	18.14%	0	0	63	87	171	268	359	308	235	68	0	0
Wheat	16.33%	92	132	219	273	186	0	0	0	0	0	0	49
Other Hay (use alfalfa)	6.84%												
Alfalfa_Seed	5.06%	0	93	183	230	273	198	183	135	0	0	0	0
***Citrus**	1.74%	70	79	127	159	192	216	235	196	180	138	97	81
***Peach Trees**	0.93%	55	62	123	196	269	298	318	264	243	186	130	90
Cauliflower	0.85%	106	21	0	0	0	0	0	0	21	130	108	112
***Misc. Field Crops**	0.78%	11	61	211	286	165	0	0	0	0	0	0	0
Average	4.26%	72	77	159	209	218	256	283	234	185	106	115	86

Weighting Factors	Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
Alfalfa	14.5	21.4	42.1	52.8	62.6	68.9	73.7	61.2	56.2	29.9	23.5	16.6
Lettuce	22.7	15.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	29.9	24.6
Cotton	0.0	0.0	11.5	15.9	31.0	48.7	65.2	55.9	42.7	12.3	0.0	0.0
Wheat	15.0	21.5	35.7	44.6	30.3	0.0	0.0	0.0	0.0	0.0	0.0	8.0
Other Hay (use alfalfa)	4.3	6.4	12.5	15.8	18.7	20.5	22.0	18.2	16.8	8.9	7.0	5.0
Seed (assumed alfalfa seed)	0.0	4.7	9.3	11.7	13.8	10.0	9.3	6.8	0.0	0.0	0.0	0.0
Citrus	1.2	1.4	2.2	2.8	3.3	3.8	4.1	3.4	3.1	2.4	1.7	1.4
Nuts (used peach trees)	0.5	0.6	1.1	1.8	2.5	2.8	3.0	2.5	2.3	1.7	1.2	0.8
Cauliflower	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.1	0.9	0.9
Other Field	0.1	0.5	1.6	2.2	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	3.1	3.3	6.8	8.9	9.3	10.9	12.1	10.0	7.9	4.5	4.9	3.7
Sum (mm)	62.4	75.7	122.9	156.5	172.8	165.6	189.2	158.0	129.1	81.6	69.2	61.1
Sum (in)	2.5	3.0	4.8	6.2	6.8	6.5	7.5	6.2	5.1	3.2	2.7	2.4

Annual Totals WMID

CVWD Monthly ETc (mm)		1	2	3	4	5	6	7	8	9	10	11	12
		56	86	118	149	181	212	244	276	307	339	370	402
		31	29	31	30	31	30	31	31	30	31	30	31
Crop CVWD	% Dist	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
ETo		74	111	172	194	277	289	275	262	227	148	96	79
Citrus	22.32%	52	77	120	136	198	211	204	195	169	110	72	59
Grapes	21.18%	26	49	107	151	225	232	203	171	128	72	38	25
Dates	8.85%	93	138	215	246	372	405	385	367	311	198	125	100
Corn	7.21%	0	78	187	241	320	0	0	0	0	0	0	0
Lettuce Late and Early	4.65%	76	79	0	0	0	0	0	0	0	61	100	81
Other Veg (Lettuce)	4.53%	76	79	0	0	0	0	0	0	0	61	100	81
Alfalfa	3.05%	0	91	174	197	281	293	279	266	230	78	0	0
Alfalfa_winter	incl	62	0	0	0	0	0	0	0	0	34	101	85
Sudan	2.69%	0	0	0	0	123	255	268	256	220	0	0	0
Broccoli	2.61%	78	70	0	0	0	0	0	0	0	83	73	77
Carrots	2.51%	79	118	182	73	0	0	0	0	0	49	80	80
Average	20.40%	68	87	164	174	253	279	268	251	212	83	86	74
	100.00%												

Weighting Factors	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
Citrus	11.6	17.3	26.9	30.4	44.1	47.0	45.5	43.6	37.7	24.7	16.0	13.3
Grapes	5.5	10.3	22.6	32.0	47.6	49.2	42.9	36.2	27.1	15.2	8.0	5.3
Dates	8.2	12.2	19.0	21.8	33.0	35.8	34.1	32.4	27.5	17.5	11.0	8.9
Corn	0.0	5.6	13.5	17.4	23.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lettuce	3.5	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	4.6	3.8
Other Veg (Lettuce)	3.4	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	4.5	3.7
Alfalfa	1.9	2.8	5.3	6.0	8.6	8.9	8.5	8.1	7.0	3.4	3.1	2.6
Sudan	0.0	0.0	0.0	0.0	3.3	6.9	7.2	6.9	5.9	0.0	0.0	0.0
Broccoli	2.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.9	2.0
Carrots	2.0	3.0	4.6	1.8	0.0	0.0	0.0	0.0	0.0	1.2	2.0	2.0
Average	13.8	17.6	33.5	35.5	51.7	56.9	54.6	51.2	43.2	16.9	17.5	15.0
Sum (mm)	51.9	77.8	125.5	144.8	211.3	204.8	192.7	178.4	148.5	86.7	68.7	56.5
Sum (in)	2.0	3.1	4.9	5.7	8.3	8.1	7.6	7.0	5.8	3.4	2.7	2.2

Annual Totals CVWD	Year	Inches	Feet
	1988	60.9	5.08
	1989	55.9	4.66
	1990	55.6	4.64
	1991	54.2	4.52
	1992	54.7	4.56
	1993	61.3	5.11
	1994	58.0	4.83
	1995	59.9	4.99
	1996	60.4	5.03
	1997	60.2	5.01
		58.1	4.8

CVWD Monthly ETc (mm)		13	14	15	16	17	18	19	20	21	22	23	24
		434	463	495	526	558	589	621	653	684	716	747	779
		31	28	31	30	31	30	31	31	30	31	30	31
Crop CVWD	% Dist	Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
ETo		83	109	161	197	225	248	243	260	209	152	85	56
Citrus	22.32%	58	76	113	138	161	181	180	193	156	113	64	42
Grapes	21.18%	29	49	99	153	183	199	178	168	118	73	34	18
Dates	8.85%	103	136	201	250	303	347	340	363	286	203	111	71
Corn	7.21%	0	76	169	244	268	0	0	0	0	0	0	0
Lettuce Late and Early	4.65%	84	71	0	0	0	0	0	0	0	70	89	58
Other Veg (Lettuce)	4.53%	84	71	0	0	0	0	0	0	0	70	89	58
Alfalfa	3.05%	0	90	163	199	228	252	246	263	212	79	0	0
Alfalfa_winter	incl	70	0	0	0	0	0	0	0	0	39	90	60
Sudan	2.69%	0	0	0	0	102	220	237	253	203	0	0	0
Broccoli	2.61%	88	62	0	0	0	0	0	0	0	83	65	55
Carrots	2.51%	89	116	171	80	0	0	0	0	0	58	72	57
Average	20.40%	76	83	153	177	208	240	236	248	195	88	76	52
	100.00%												

Weighting Factors		Jan-89	Feb-89	Mar-89	Apr-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89	Nov-89	Dec-89
Citrus		12.9	17.0	25.2	30.8	35.9	40.3	40.2	43.2	34.7	25.2	14.2	9.4
Grapes		6.1	10.3	20.9	32.4	38.7	42.2	37.7	35.6	25.0	15.5	7.1	3.7
Dates		9.1	12.0	17.8	22.1	26.8	30.7	30.1	32.1	25.3	17.9	9.8	6.3
Corn		0.0	5.5	12.2	17.6	19.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lettuce		3.9	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	4.1	2.7
Other Veg (Lettuce)		3.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	4.0	2.6
Alfalfa		2.1	2.7	5.0	6.1	7.0	7.7	7.5	8.0	6.5	3.6	2.7	1.8
Sudan		0.0	0.0	0.0	0.0	2.8	5.9	6.4	6.8	5.5	0.0	0.0	0.0
Broccoli		2.3	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.7	1.4
Carrots		2.2	2.9	4.3	2.0	0.0	0.0	0.0	0.0	0.0	1.5	1.8	1.4
Average		15.4	16.9	31.1	36.1	42.3	48.9	48.2	50.6	39.7	17.9	15.6	10.7
Sum (mm)		58.0	75.6	116.5	147.0	172.8	175.8	170.1	176.4	136.7	90.2	61.1	40.1
Sum (in)		2.3	3.0	4.6	5.8	6.8	6.9	6.7	6.9	5.4	3.6	2.4	1.6

Annual Totals CVWD

Attachment 8

California Regional Water Quality Control Board. (2003). "Bacterial Indicators Total Maximum Daily Load for the Palo Verde Outfall Drain, Riverside and Imperial Counties, California."

BACTERIAL INDICATORS
TOTAL MAXIMUM DAILY LOAD
FOR THE PALO VERDE OUTFALL DRAIN
Riverside and Imperial Counties, California

DRAFT

April 10, 2003

California Regional Water Quality Control Board
Colorado River Basin Region
Palm Desert, California

1. INTRODUCTION

The Palo Verde Lagoon and Outfall Drain are located in the Palo Verde Valley which lies in both Riverside and Imperial Counties of California. Agriculture in the valley is sustained by irrigation water provided by the Palo Verde Irrigation District (PVID). The valley has a system of agricultural drains that include a large outfall drain and a lagoon around which the community of Palo Verde is centered. The Palo Verde Outfall Drain (PVOD) discharges its waters into the Colorado River at the Cibola National Wildlife Refuge (CRWQCB 2002, QAPP). Figure 1.1, shows the entire Palo Verde Valley. Figure1.2 shows the area of the community and the Lagoon.

The State Board's 303(d) list of impaired waterbodies identifies the Palo Verde Outfall Drain as water quality limited because pathogen concentrations violate water quality objectives that protect the following beneficial uses: contact and non-contact water recreation (REC I and REC II); warm freshwater habitat (WARM); wildlife habitat (WILD); and preservation of rare, threatened, or endangered species (RARE).

The purpose of the Palo Verde Outfall Drain Pathogen Total Maximum Daily Load (TMDL) is to protect Palo Verde Outfall Drain beneficial uses by reducing pathogen concentrations in the water. The Palo Verde Outfall Drain discharges to the Colorado River upstream of the River's outlet to the Sea of Cortez in Mexico.

A TMDL is defined as the sum of the individual waste load allocations (WLAs) for point sources of pollution, plus the sum of the load allocations (LAs) for nonpoint and natural background sources of pollution, plus a margin of safety (MOS), such that the capacity of the waterbody to assimilate pollutant loadings without violating water quality objectives is not exceeded. That is,

$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{MOS}$$

where $\sum$ = sum, WLA = waste load allocation (for point sources), LA = load allocation (for nonpoint and natural background sources), and MOS = margin of safety.

This TMDL addresses Palo Verde Outfall Drain pathogen impairments, and identifies allowable pathogen loads for point and nonpoint sources discharging into the Palo Verde Outfall Drain. When allowable loads are achieved, they are expected to eliminate pathogen-caused impairments.

After examining the potential point and nonpoint source contributions of bacteria to the Palo Verde Outfall Drain, modeling scenarios conducted by Tetra Tech, Inc. show the majority of bacteria loading to the Palo Verde Outfall Drain appear to originate from natural background sources. Assuming a septic system failure rate of 20% in the model, waterfowl contribute about 97% of bacteria while septic systems contribute less than one percent. (See discussion on page 32).

Attachment 9A

Coachella Valley Water District. (1997). "Severe Groundwater Overdraft – Possible Strategies and Opportunities."

Coachella Valley Water Problem:

Severe Groundwater Overdraft

"Possible Strategies and Opportunities"

1997

Coachella Valley Water District

COACHELLA VALLEY WATER DISTRICT
P.O. BOX 1058
COACHELLA, CA 92236
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TABLE OF CONTENTS

Section 1
Introduction and Summary

The Coachella Valley Water District (District), located in Southern California, was formed in 1918 under the California Water Code provisions of the County Water District Act.

A governing Board of Directors with five members representing individual divisions are elected to four-year terms.

Nearly 640,000 acres are within the District boundaries, mostly in Riverside County but the District also extends into San Diego and Imperial counties.

The District provides six water service categories:

- irrigation water,
- domestic water,
- stormwater protection,
- agricultural drainage,
- wastewater reclamation and reuse, and
- water conservation.

Recreation and the generation of energy are incidental benefits of some of the water service activities.

Water Problem

Severe Groundwater Overdraft

When the District was formed in 1918 the groundwater table was dropping. Farmers were using more water and artesian wells had ceased flowing. The District signed its first contract with the federal government for Colorado River water supplies in 1919. Water levels continued to drop (in the lower valley wells were 40 to 50 feet lower) until Colorado River deliveries began in 1949. When farmers converted from wells to Colorado River water supplies, the water level recovered within 15 years (1965).

However, water demands increased in the 1980s to such an extent that water levels have dropped to their lowest level. As a result, the District has begun preparation of a *Water Management Plan* to eliminate the groundwater overdraft. Sophisticated groundwater modeling and analysis is currently under way to determine the best groundwater management strategies.

Strategies and Opportunities

- Implementation of water conservation measures (best management practices, BMPs) for urban water use, including "state-of-the-art" outdoor irrigation technology (CIMIS) for golf courses and other large landscape areas.

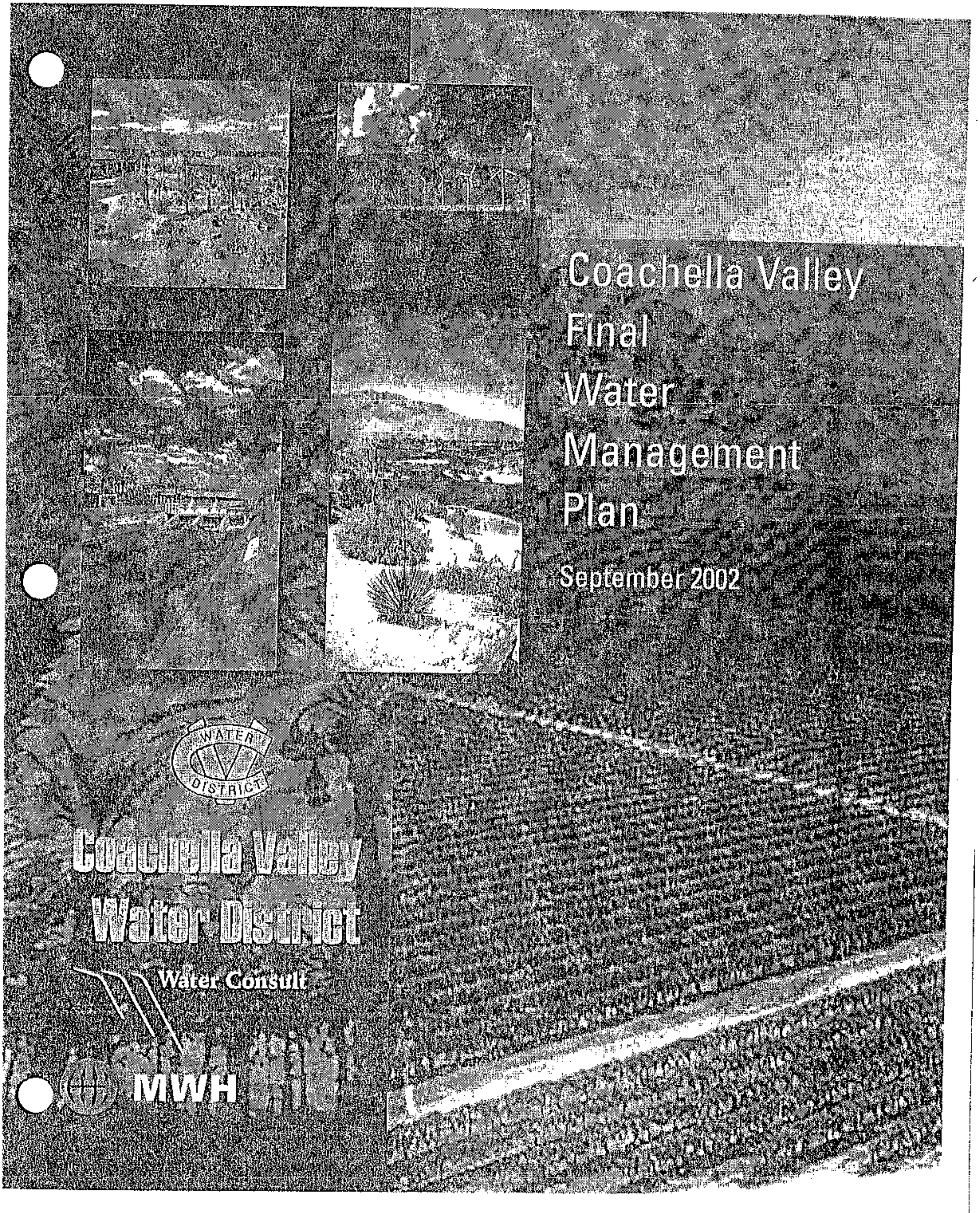
- Use recycled water through canal water delivery system to avoid capital cost of constructing new pipeline distribution systems.

Attachment 9B

Coachella Valley Water District. (2002). "Coachella Valley Water Management Plan."

Coachella Valley Final Water Management Plan

September 2002



Coachella Valley Water District

Water Consult

MWH

COACHELLA VALLEY WATER MANAGEMENT PLAN

Prepared by:

Coachella Valley Water District

P.O. Box 1058
Coachella, California 92236
(760) 398-2651

Thomas E. Levy
General Manager-Chief Engineer

Steve Robbins
Assistant General Manager

September 2002

Attachment 10

Grisмer, M. E. and Bali, K. M. (1996). "Continuous Ponding and Shallow Aquifer Pumping Leaches Salts in Clay Soils." California Agriculture, Vol. 51, No. 3.

California Agriculture - Oakland, CA - 05/06/97 - 34

Publication - City & State - Publication Date - Section/Page IMPERIAL IRRIGATION DISTRICT - News Clips

Suzanne Paisley

◀ With continuous ponding for 1 month, scientists were able to leach salts deeper in the heavy clay soil at the UC Desert Research & Extension Center.

Continuous ponding and shallow aquifer pumping leaches salts in clay soils

Mark E. Grismer ❑ Khaled M. Bali

Poor water penetration and high soil salinity can be particularly detrimental to crop production in arid regions. In the Imperial Valley, roughly half of the crop acreage is planted on clay soils with very low water infiltration rates. A 30-year study showed that traditional subsurface-drainage systems provide limited control of soil water content and salinity in the root zone in clay soils underlain by artesian aquifers. In a more recent 3-year study at the UC Desert Research & Extension Center, a shallow drainage-well system improved water movement through the soil profile and was useful in leaching salts from clay soils only after continuous surface ponding and groundwater pumping. Continuous ponding for 1 month was sufficient to leach some of the salt deeper in the heavy soil.

Water penetration problems are common on agricultural lands and can be particularly detrimental to crop production in arid regions, where poor water penetration results in inadequate leaching to control soil salinity in the root zone. In the Imperial Valley, clay soils with very low water infiltration rates occur on roughly half of the planted acreage. High soil salinity is often associated with these soils because water preferentially flows through cracks that form as the soils dry, rather than percolating through the soil and leaching out salts. Excessive soil salinity in these clay fields limits crop production to salt-tolerant forage and cereal grains, which may have reduced yields depending on the prevailing soil salinity in the field at germination.

We have been investigating the drainage and leaching process in clay soils of the UC Desert Research & Extension Center (DREC) near Holtville for the past decade, building on work conducted by Robinson, Luthin and others in the previous three decades. We have found that a shallow artesian sand aquifer underlying the clay soil contributes to the relative inefficiency of tile drainage systems in these soils. The ineffectiveness of the existing subsurface drainage system was demonstrated when we plugged it in three different areas of the station and observed little change in soil salinity and groundwater levels from year to year.

Attempts to address the low permeability and high salinity problems associated with the clay soils have included continuous flooding (ponding) for periods of days to weeks, intermittent flood irrigations, use of infiltration water amendments such as gypsum, Wetsol, Spersal and combinations thereof and installation of more aggressive (narrowly spaced) subsurface drainage systems. While each approach may be recommended in particular settings, each has had limited success and none has successfully eliminated the salinity problems of the clay soils.

The DREC lands are entirely underlain by a fine-sand saline aquifer with a flow gradient toward the Salton Sea that maintains high soil salinity and moisture levels in the clay at depths of 3 to 5 feet. When Donnan and Blaney (1954) conducted their original leaching studies, they noted the presence of this aquifer beneath the "Meloland Field Station" (as the DREC was called then, and still is by local residents). They found that the drainage system continued to remove considerably more salt than was initially available in the soil profile, so that leaching failed to provide a simple mass balance of salts. More recent measurements by our group show that the shallow aquifer is the source of these excess salts.

The conventional subsurface drainage systems (tiles) have been largely ineffective in controlling the salinity problems associated with this shallow artesian aquifer. In an effort to remedy this situation, we have installed a shal-

Attachment 11

Grismer, M. E. and Bali, K. M. (1998). "Subsurface Drainage Systems Have Little Impact On Water Tables, Salinity of Clay Soils." California Agriculture, Vol. 52, No. 5.

formance as a success. This year has been a tremendous learning experience for water districts and farmers alike. The drainage incentive fee imposed on the Grasslands Area farmers for the selenium load overage will be placed in an account. The funds will be directed to projects that will help further reduce selenium drainage.

A unique feature of the Grasslands Bypass Project is the spirit of cooperation between water districts in this novel program. Rather than attempting to legally define each water district's share of the collective selenium discharge target load, the participants have chosen to work as one unit in meeting goals, allowing participating water districts to strive to implement best management practices at their own pace. The advances made in the past 12 months have been an intensive learning experience for water districts and individual growers alike as they seek ways to develop sustainable agronomic techniques that meet environmental policy goals and water-quality objectives for the San Joaquin River.

N.W.T. Quinn is Staff Geological Scientist, Lawrence Berkeley National Laboratory, and Water Resources Engineer, U.S. Bureau of Reclamation, Sacramento; J.C. McGahan is Principal Engineer, Summers Engineering Inc., Hanford; and M.L. Delamore is Chief Drainage Section, U.S. Bureau of Reclamation, Fresno.

Further reading

Quinn NWT. 1995. A compliance monitoring program for use and operation of the Grasslands Bypass for drainage conveyance in the western San Joaquin Valley. Lawrence Berkeley National Laboratory Topical Report, LBNL-39052, Berkeley, CA 94720.

Quinn NWT, Chen CW, Grober LF, et al. 1997. Real-time management of water quality in the San Joaquin River. Cal Ag 51(5):14-20.

Summers Engineering Inc. 1997. Summary of Grassland Basin Drainers Drainage Reduction Activities. Meeting package for Grasslands Bypass project tour.

USBR. 1996. Proposed monitoring program for use and operation of the Grasslands Bypass to remove agricultural drainage from Grassland Water District channels. Sacramento, CA.

Subsurface drainage systems have little impact on water tables, salinity of clay soils

Mark E. Grismer □ Khaled M. Bali

Subsurface drainage systems are traditionally installed in agricultural fields to control waterlogging (high water tables) and excess salinity affecting the crop root zone. However, in many clay fields of the Imperial Valley underlain by shallow fine-sand aquifers, the drains may be ineffective and provide limited relief for the root zone. After extensive work considering soil-water flow paths in a particular field at the UC Desert Research and Extension Center (DREC), we plugged whole-field drainage systems, then evaluated the impact on water-table levels and soil salinity during a 3-year period. We found that the shallow fine-sand aquifer underlying the DREC, originally identified in the 1950s, combined with the Imperial Irrigation District deep-ditch system, provided sufficient drainage relief for several areas of the DREC to successfully grow a variety of crops. Given the ineffectiveness of subsurface drainage systems in three different fields that had soil characteristics similar to more than half the Imperial Valley fields we expect that in many parts of the valley, augmentation of subsurface drainage systems through "splitting" the lateral drainline spacing may not be warranted. Indeed, efforts to reduce the salinity of heavier soils on the DREC, or elsewhere in the valley, may be better directed at improving water penetration and leaching of soils through deep ripping or other cultivation/mulching methods, rather than expending resources on improving the subsurface drainage system.

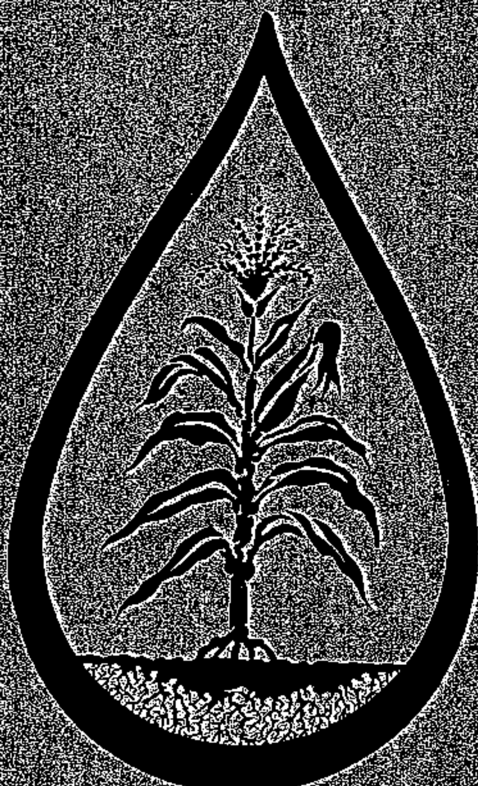
Subsurface drainage systems are traditionally installed in agricultural fields to control waterlogging (high water tables) and excess salinity affecting the crop root zone. The conceptual basis for such systems is simply to provide an artificial "outlet" for the excess water and salts in the soil resulting from regular irrigation (or from rainfall in humid areas). Although proper identification of the source of the excess water and salinity is important to the design of these systems, in many arid regions that source is assumed to be (and often is) excess irrigation recharge resulting from less-than-perfect application efficiency and distribution uniformity. In some cases, however, a more detailed field investigation may be appropriate to identify other possible sources of excess water and salinity.

We have been investigating the performance of subsurface drainage systems at the UC Desert Research and Extension Center (DREC) for the past three decades to determine their value relative to control of shallow groundwater levels and root-zone soil salinity (Grismer et al. 1988). In the cracking, or heavy clay, soils found on the DREC and in over 40% of the valley, the drains are relatively ineffective in

Attachment 12

Hill R. W., Johns E. L., and Frevert D. K. (1983). "Comparison Of Equations Used For Estimating Agricultural Crop Evapotranspiration With Field Research." U.S. Department of Interior, Bureau of Reclamation, 3-42.

Comparison of Equations Used for Estimating Agricultural Crop Evapotranspiration with Field Research



Bureau of Reclamation

U. S. Department of the Interior

CHAPTER 1. STUDY DESCRIPTION, PURPOSE, AND SCOPE

Water requirement information is essential in irrigation project planning. It is the basis for designing project and farm irrigation systems, and is used in quantifying equitable water rights. Crop water use estimates are also important in the analysis of operating projects or in basinwide water utilization surveys. For example, water requirement information is essential in determining the life of a nonrenewable water resource such as deep ground-water aquifers. Increased competition for a limited resource and current emphasis on conservation and water quality require accuracy of water requirement estimates.

Much research has been directed at identifying the water requirements of plants, particularly irrigated crops. Past research involved precision lysimeters and experimental field studies where the water budget was closely monitored to determine the ET (evapotranspiration). Much of this research was directed toward conditions where water was not a limiting factor or conditions were relatively conducive to high yields and high water use. Recently, research has been conducted under a range of water supply conditions such as line source experiments. This research opened the way for the new concept in determining water requirements discussed in this report.

Ideally, field research data should be utilized directly in estimating crop water requirements. Since this information is not available or may not be directly applicable in every locality, planners must rely on experience in neighboring projects or upon theoretical estimates. The principal factors influencing the amount of irrigation water required by plants are: (1) climatic factors such as precipitation, temperature, solar radiation, etc.; plant characteristics; and (3) local cultural

Attachment 13

Imperial Irrigation District. (1989-1997). "Imperial Irrigation District Annual Inventory of Areas Receiving Water."

IMPERIAL IRRIGATION DISTRICT

ANNUAL INVENTORY OF AREAS RECEIVING WATER

YEARS 1997, 1996, 1995

I. CROP SURVEY

GARDEN CROPS	ACRES 1997	1996	1995
ARTICHOKE	378	228	375
ARTICHOKE (SEED)	10	0	0
BEANS	203	355	51
BLACKEYED PEAS	314	0	0
BROCCOLI	6,480	6,311	5,926
BROCCOLI (SEED)	23	207	20
CABBAGE	961	710	757
CABBAGE (SEED)	20	0	0
CABBAGE, CHINESE	5	0	0
CARROTS	16,014	16,469	14,959
CARROTS (SEED)	5	138	336
CAULIFLOWER	2,553	2,776	2,762
CAULIFLOWER (SEED)	11	2	30
CELERY	204	109	94
CELERY (SEED)	32	0	0
CHICORY	0	6	6
CHINESE GRASS	0	10	25
COLLARDS	10	0	0
CUCUMBERS	0	19	44
EAR CORN	5,500	4,372	3,896
EGGPLANT	5	70	68
ENDIVE	55	0	0
ENDIVE (SEED)	0	150	0
FLOWERS	125	94	107
FLOWERS (SEED)	40	50	49
GARBANZO BEANS	1,034	1,211	75
GARLIC	165	437	335
HERBS, MIXED	17	13	0
HERBS, MIXED (SEED)	200	0	0
KALE	54	0	107
LETTUCE	15,971	16,299	16,802
LETTUCE (SEED)	20	0	0
LETTUCE, BUTTER	0	0	93
LETTUCE, CHINESE	0	0	4
LETTUCE, GREEN	33	70	70
LETTUCE, RED	0	100	262
LETTUCE, ROMAINE	1,505	600	809
LETTUCE, MIXED	2,663	2,230	2,476
MELONS			
CANTALOUPES, FALL	2,138	0	455
CANTALOUPES, SPRING	11,397	13,337	14,476
CRENSHAW, SPRING	15	0	0
HONEYDEW, FALL	160	316	74
HONEYDEW, SPRING	688	682	478
KAVA	20	0	0
MIXED, FALL	108	5	0
MIXED, SPRING	1,087	505	533
WATERMELONS	2,419	2,822	2,619
WATERMELONS (SEED)	1	0	0
MUSTARD	178	122	0
MUSTARD (SEED)	13	15	17
OKRA	91	96	77
OKRA (SEED)	44	0	0
ONIONS	10,176	13,324	11,258
ONIONS (SEED)	3,573	1,882	1,317
PARSLEY	2	0	0
PARSNIPS	42	0	50
PEAS	0	0	16
PEAS (SEED)	7	7	0
PEPPERS, BELL	459	568	642
PEPPERS, HOT	56	39	291
POTATOES	2,784	2,538	1,923
RADISHES	37	146	73
RADISHES (SEED)	8	0	16
RAPINI	722	704	744
RHUBARB	0	10	10
RUTABAGAS	81	0	0
SPINACH	646	372	345
SPINACH, CHINESE	0	22	0
SQUASH	150	59	223
SQUASH (SEED)	9	0	12
SWEET BASIL	150	120	0
SWISS CHARD	40	0	0
TOMATOES, FALL	22	0	149
TOMATOES, SPRING	840	2,022	1,836
TURNIPS	377	193	198
VEGETABLES, MIXED	1,761	803	1,663
VEGETABLES, MIXED (SEED)	15	13	12
WATERLILIES	84	110	80
TOTAL GARDEN CROPS	95,030	93,868	90,121

FIELD CROPS	ACRES 1997	1996	1995
ALFALFA, FLAT	117,388	113,429	185,512
ALFALFA, ROW	43,594	39,405	0
ALFALFA (SEED)	14,248	13,238	13,423
ALICIA GRASS	1	1	1
BAMBOO	81	15	0
BARLEY	91	58	606
BERMUDA GRASS	24,301	20,952	21,704
BERMUDA GRASS (SEED)	20,613	22,636	17,854
BUFFLE GRASS	112	169	184
COTTON	3,970	4,601	6,881
DICHONDRA GRASS	0	0	95
DUNALIELLA	25	25	25
FIELD CORN	1,683	453	734
FLAX	4	8	18
GRASS, MIXED	64	29	476
HEMP	0	0	498
KENAF	3	16	0
KLIEN GRASS	567	452	135
LEMON GRASS	5	5	79
OATS	1,753	1,267	2,063
RAPE	778	773	919
RED BEETS	30	23	13
RICE	0	0	10
RYE GRASS	4,600	2,978	4,685
RYE GRASS (SEED)	0	37	37
SAFFLOWER	0	0	74
SESBANIA	322	120	514
SORGHUM GRAIN	255	2,536	20
SORGHUM SILAGE	376	100	517
SPIRULINA ALGAE	70	70	70
SUDAN GRASS	83,562	81,896	77,383
SUDAN GRASS (SEED)	310	300	151
SUGAR BEETS	39,327	33,980	31,612
SUGAR CANE	80	79	82
WHEAT	90,005	106,513	62,117
TOTAL FIELD CROPS	448,238	446,164	428,492

PERMANENT CROPS	ACRES 1997	1996	1995
ASPARAGUS	5,337	4,919	5,265
CITRUS			
GRAPEFRUIT	1,194	1,200	1,157
LEMONS	1,834	1,161	811
MIXED	278	78	29
ORANGES	760	667	667
TANGERINES	662	662	662
DATES	82	82	42
DUCK PONDS (FEED)	8,837	8,798	7,994
EUCALYPTUS	14	14	15
FISH FARMS	1,263	1,173	1,173
FRUIT, MIXED	10	10	10
GUAR BEANS	104	276	20
JOJOBA	202	400	1,943
MANGOS	150	150	150
NURSERY	24	24	24
ORNAMENTAL TREES	15	5	5
PALMS	78	84	84
PASTURE, PERMANENT	722	696	728
PEACHES	2	2	85
PECANS	17	27	27
TOTAL PERMANENT CROPS	21,605	20,428	20,891

	1997	1996	1995
TOTAL ACRES OF CROPS	564,873	560,460	539,504

NOTE: CROPS ARE LISTED FOR THE YEAR IN WHICH THEY ARE PREDOMINATELY HARVESTED.

IMPERIAL IRRIGATION DISTRICT
ANNUAL INVENTORY OF AREAS RECEIVING WATER
YEARS 1994, 1993, 1992

I CROP SURVEY

	ACRES 1994	ACRES 1993	ACRES 1992
GARDEN CROPS			
Beans	3	0	0
Blackeyed Peas	57	0	0
Broccoli	6,406	6,406	8,889
Broccoli (Seed)	91	10	33
Cabbage	1,483	1,483	1,011
Cabbage, Chinese	35	28	66
Carrots	16,312	16,312	15,557
Carrots (Seed)	76	93	117
Cauliflower	3,755	3,755	6,237
Cauliflower (Seed)	105	91	51
Celery	58	67	629
Chickory	35	3	0
Chinese Grass	25	3	0
Cucumbers	12	0	11
Ear Corn	4,491	2,879	3,830
Eggplant	5	5	30
Flowers	25	25	42
Flowers (Seed)	81	128	195
Garlic	457	85	414
Herbs, Mixed	0	123	133
Herbs, Mixed (Seed)	0	21	59
Lettuce	17,288	20,705	21,686
Lettuce, Butter	3,757	120	120
Lettuce, Chinese	4	25	25
Lettuce, Romaine	832	893	1,024
Lettuce (Red)	262	104	104
Melons			
Cantaloupes, Fall	246	525	262
Cantaloupes, Spring	14,093	13,057	12,042
Casaba, Fall	0	0	73
Casaba, Spring	0	0	32
Crenshaw, Fall	0	0	2
Crenshaw, Spring	0	58	38
Honeydew, Fall	203	0	140
Honeydew, Spring	579	335	92
Mixed, Fall	233	79	0
Mixed, Spring	530	225	67
Watermelons	3,498	2,596	2,485
Watermelons (Seed)	78	0	0
Kale	245	214	182
Mustard	7	0	12
Mustard (Seed)	0	43	0
Okra	42	112	0
Okra (Seed)	63	3	0
Onions	12,004	10,767	10,126
Onions (Seed)	1,929	2,315	2,790
Parsley	1	75	0
Parsnips	144	107	50
Peas	2		
Peppers, Bell	588	332	352
Peppers, Hot	71	71	27
Peppers, Sweet	1	20	5
Potatoes	1,304	970	604
Radishes	36	52	49
Radish (Seed)	13		
Rapini	546	589	520
Rutabagas	1	10	12
Spinach	366	451	169
Spinach, Chinese	22	40	0
Squash	220	102	187
Squash (Seed)	0	16	0
Swiss Chard (Seed)	0	16	0
Tomatoes, Fall	0	958	0
Tomatoes, Spring	3,486	1,892	3,483
Turnips	238	179	188
Vegetables	2,134	2,059	1,178
Vegetables, Mixed (Seed)	12	0	8
Water Lilies	124	104	0
Total	98,714	91,736	95,638
FIELD CROPS			
Alfalfa	188,309	182,910	186,205
Alfalfa (Seed)	6,675	7,949	7,099
Alicia Grass	1	1	71
Barley	239	182	92
Bermuda Grass	17,056	17,367	15,359
Bermuda Grass (Seed)	17,535	20,494	19,098
Buffle Grass	283	525	0
Canola	408		
Cotton	6,891	7,255	4,227
Dunaliella	25	25	25
Field Corn	405	477	178
Flax	13	121	0
Grass, Mixed	28	30	14
Kenaf	0	0	80
Klein Grass	135		
Oats	1,539	1,262	1,981
Rape	150	45	0
Red Beets	38	69	0
Rice	10	10	0
Rye Grass	5,867	6,227	9,591
Rye Grass (Seed)	0	162	162
Safflower	80	942	0
Sesbania	256	47	110
Sesbania (Seed)	0	106	190
Sorghum Grain	113	98	68
Sorghum Sileage	388	314	176
Soy Beans	80		
Spirulina Algae	20	20	20
Sudan Grass	78,878	57,850	53,352
Sudan Grass (Seed)	266	273	72
Sugar Beets	34,802	41,492	39,703
Sugarcane	12	18	0
Wheat	58,247	59,283	69,180
Total	418,749	405,554	407,053
PERMANENT CROPS			
Artichoke	360	563	560
Asparagus	6,136	6,111	6,466
Citrus			
Grapefruit	1,078	1,036	920
Lemons	799	789	691
Mixed	29	29	33
Oranges	632	632	525
Tangerines	625	626	440
Dates	42	42	18
Duck Ponds (Feed)	8,070	8,243	8,244
Eucalyptus	15	23	17
Fish Farms	1,173	1,175	903
Fruit, Mixed	10	15	165
Jojoba	2,017	2,017	2,117
Mangos	150	150	0
Nursery	24	24	24
Ornamental Trees	5	5	0
Palms	69	69	69
Pasture, Permanent	798	695	610
Peaches	145	229	198
Pecans	27	27	27
Total	22,204	22,500	22,027
Total Acres of Crops	539,667	519,790	524,718

Attachment 14

Kaddah, M. T. and Rhoades, J. D. (1976). "Salt and Water Balance in Imperial Valley, California." Soil Science Society of America Journal, Vol. 40, 93-100.

EXHIBIT 19

Salt and Water Balance in Imperial Valley, California[1]

M. T. KADDAH AND J. D. RHOADES[2]

ABSTRACT

Salt balance ($SB = V_{eff.w} \cdot C_{eff.w} - V_{inf.w} \cdot C_{inf.w}$) of the Imperial Valley (IV) has been determined annually since 1943 by the Imperial Irrigation District. Salinity trends in the valley are assessed from biweekly measurements of the volume, V, and concentration, C, of influent, inf.w, and effluent, eff.w, waters. In this paper we summarize the SB data, evaluate their significance, and suggest approaches for assessing salinity trends in the soils of the valley.

The SB data reflected the cropping and water use patterns in the valley. However, the data were insufficient to distinguish origin of water and salt in effluent waters or to provide information about changes in root zone salinity. In 1973 total evapotranspiration (ET) by crops in the valley was estimated to be 229 × 10⁷ ha-m, equivalent to 70% of the water delivered to the farmers. Deductions as to Cl^- composition of influent and effluent during 1973 suggest that the Cl^- load in the effluent water was contributed as follows: 54.7% from ground water, 35.0% from root zone drainage water, and 10.3% from tail water (runoff).

A more definitive interpretation of the salt balance data would require more accurate evaluation of volume of tail and consumptive use waters and volume and concentration of root zone percolate. If this information cannot be obtained on a valley-wide basis, then an alternative approach is to establish a representative number of soil salinity monitoring plots through the valley and assess their root zone salinity periodically.

Additional Index Words: **Influent water, effluent water, root zone salinity, ground water salinity, surface run-off.**

SALT BALANCE was defined by Scofield (12) as "the relation between the quantity of dissolved salts delivered to an irrigated area with the irrigation water and the quantity removed from the area by the drainage water". The relation was expressed as:

$$\text{salt output } (V_{eff.w} \times C_{eff.w}) - \text{salt input } (V_{inf.w} \times C_{inf.w}) = \text{salt balance (SB)}$$

where $V_{eff.w}$ and $V_{inf.w}$ are the volumes of effluent (drainage) and influent (irrigation) water, and $C_{eff.w}$ and $C_{inf.w}$ are the soluble salt concentration in effluent and influent water, respectively. Sometimes the salt balance is reported as the ratio of output to input salts, which is referred to as the salt balance index (13). Scofield (12) acknowledged the limitations of the SB concept; since the drainage output "may be in error by the amount of quantities (of salt) absorbed (by the plant), precipitated, or decomposed". Similarly, "outflowing drainage water may represent largely water displaced from the subsoil reservoir, and under these conditions there may long continue for the area as a whole a favorable salt balance, and yet with inadequate root zone leaching there may be progressive and harmful accumulation of salts in the root zone". In spite of these limitations salt balance calculations are frequently advocated for indicating the trends in salinity in irrigated projects (1, 13). Since 1943, the Imperial Irrigation District (IID) has published annual SB reports following the procedures suggested by Scofield (11, 12). From 1953 through 1958, the SB reports included only the total salts. Since 1959, the anion and cation content of the irrigation and drainage waters have also been included.

This paper summarizes and evaluates the SB reports of the Imperial Valley District in the light of present knowledge of the soil properties of the valley, soil salinity, and existing water management practices.

PHYSIOGRAPHY, SOIL PROPERTIES, AND IRRIGATION AND DRAINAGE SYSTEMS OF IMPERIAL VALLEY

The Imperial Valley is in extreme southern California and occupies most of the northern arm of the Colorado River Delta. It extends for about 64 km (40 miles) along the USA-Mexico International boundary on the south, where the elevation is about sea level, to the southern end of the Salton Sea on the north where the elevation is about 70 m (230 feet) below sea level. The valley is roughly bowl-shaped, with a fall ranging from 0.19–0.75% toward the center and in the direction of the Salton Sea. Irrigation was begun in the valley in 1901 by importing Colorado River water; before that the valley was a desert. The irrigated area in the valley comprises about 178,000 ha (440,000 acres), and is from 25 to 48 km (16–30 miles) wide in the east-west direction (Fig. 1).

The soils of the valley have been deposited under lacustrine, semilacustrine, and deltaic conditions within the valley and alluvial fan formations at the outer margins of the valley. They are highly stratified Entisols, and are divided into eight soil series according to the texture of the main soil section (25–100 cm depth). Soils having control sections of (i) clay and silty clay—Imperial soil series; (ii) silty clay loams, clay loams and sandy clay loams—Glenbar series; (iii) silt loams, loams, and very fine sandy loams—Indio series; (iv) fine sandy loams and loamy fine sands—Antho series; and (v) fine sands—Rositas series. Three soil series contains two major strata of contrasting textures. Soils with fine textures such as silty clay overlying loamy textures, such as sandy and silt loam fall into the Holtville series. Soils with an inverse stratification of coarse loamy over fine textures belong to the Meloland series. Local overwash of sand or gravelly sand underlain by clay textures is called the Niland series. The Imperial series belong to the Typic Torrifluvent Subgroup, the Rositas series belong to the Typic Torripsamment Subgroup, and the rest of the series belong to the Typic Torrifluvent Subgroup. The acreage percentages of the various series in the irrigated land of Imperial Valley are estimated as 44, Imperial; 15, Glenbar; 15 Holtville; 8, Meloland; 8, Antho; 6, Indio; 2, Niland; and 2, Rositas.

[1]Contribution from the Western Region, USDA, ARS. Received 9 June 1975. Approved 9 Oct. 1975.
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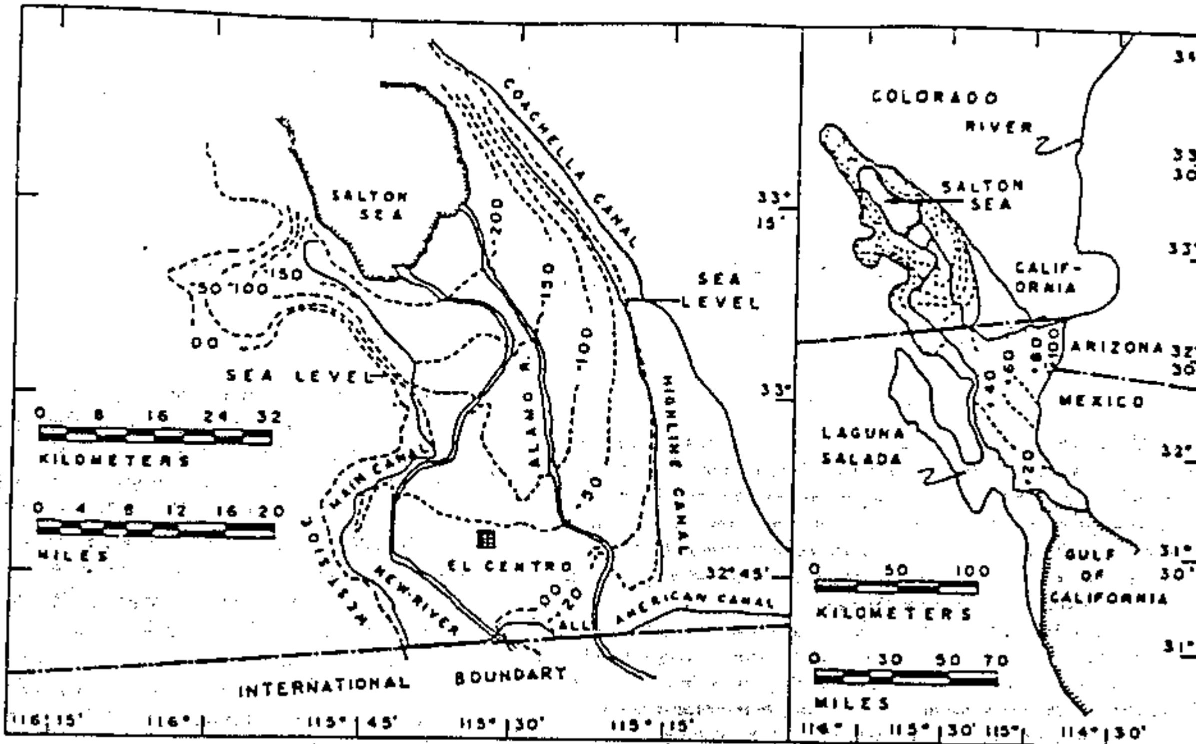

Fig. 1—Colorado River delta *(right)* and Imperial Valley *(left)*. Dashed lines represent contour intervals in feet.

The valley is intersected by an elaborate system of distributary canals and open drains constructed and maintained by the IID. These canals and drains are generally 0.8 km (0.5 miles) apart. The All American Canal, which diverts water from the Colorado River at the Imperial Dam provides all the water needed for irrigation and domestic purposes. Three branches of the All American Canal—East Highline, Central Main, and West Highline—feed the gravity-flow irrigation system through distributary canals that run parallel to open drains.

The open drains provide outlets for surface and subsurface drainage water. Except for some drains in the north that discharge into Salton Sea directly, the open drains discharge into the Alamo and New rivers, which in turn discharge by gravity-flow into the Salton Sea. Open drain construction began about 1921 to alleviate the waterlogging and salinity problems that had developed in the valley. The system was only partially successful and the need for more field subsurface drains became urgent. Farmers began to install tile drains on their land as early as 1928. Now about 156,000 ha (385,000 acres) or about 88% of the irrigated area in the valley has tile or plastic tube subsurface drains installed 1.5–1.8 m (5–6 feet) deep at spacings of 15–75 m (50–250 feet).

Intensive soil water table investigations were started in 1920 when the IID installed observation wells in roughly a 1.609-km (1-mile) grid over most of the irrigated area. Observations were made at each well every 4 months. For years 1940 and 1943 the Sept. readings showed the following distribution of water table depths (3).

	Percentages	
Depth, cm	1940	1943
0–180	43.7	30.0
180–240	20.5	28.9
below 240	35.8	41.1

The readings of the wells have been taken periodically three times a year since 1943 but no analyses or summaries of the data are available. However, general observations indicate that the percentages of areas with water tables at the 0–180 cm depth tends to decrease gradually as more areas are provided with subsurface tube drains, and concrete-lined irrigation ditches.

WATER AND SALT BALANCE MEASUREMENTS

The IID measures the amounts of water and salt, and the composition of the salt load (i) entering the valley from the All American Canal and from the Alamo and the New rivers at the USA-Mexico border and (ii) leaving the valley into the Salton Sea from the Alamo and New rivers. They also measure the amounts of water discharged directly from northern open drains into the Salton Sea; concentration of salts in these latter drains is taken as the average of the concentration in the Alamo and New rivers. Underground waters entering the south or from eastern and western borders of the valley are not measured for any salt balance calculations.

Water samples are analyzed weekly for total dissolved solids (TDS). Before 1970, TDS were determined by evaporation and drying to constant weight at 105C. Since 1970, TDS have been determined by evaporation and drying to constant weight at 180C. Samples are analyzed biweekly for HCO_3, Cl, SO_4, Ca, and Mg. These ions have been determined as follows: HCO_3, titration with 0.05*N* H_2SO_4 to methyl orange end point; Cl^-, titration with $AgNO_3$ (Mohr's method); Ca, precipitation as oxalate and titration with $KMnO_4$; SO_4, precipitation and weighing $BaSO_4$; Mg precipitation as $MgNH_4PO_4$ and weighing as $Mg_2P_2O_7$. Sodium and K are estimated by the difference between the sum (in meq) of HCO_3, Cl, and SO_4 anions and the sum of Ca and Mg cations. Because K is generally < 5% of Na, a value of Na + K has been used as a measure of Na.

RESULTS AND DISCUSSION

Water Balance

A water balance for the Imperial Valley may be calculated according to the relation:

Input = output ± change in soil and ground water storage

$$V_{inf.w} + V_{rw} = V_{cw} + V_{eff.w} \pm \Delta V_{sw} \pm \Delta V_{gw} \quad [1]$$

where input consists of the volumes of the influent, $V_{inf.w}$,

Attachment 15

Mass, E. V. (1987). "Crop Salt Tolerance" Agricultural Salinity Assessment and Management, American Society of Civil Engineers, No. 71, 262-304.

ASCE Manuals and Reports on Engineering Practice No. 71

Agricultural Salinity Assessment and Management

Kenneth K. Tanji, Editor

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CHAPTER 13

CROP SALT TOLERANCE[a]

INTRODUCTION

The salt tolerance of a plant can be defined as the plant's capacity to endure the effects of excess salt in the medium of root growth. Implicit in this definition is the idea that a plant can withstand a precise amount of salt without adverse effects. In truth, the salt tolerance of a plant is not an exact value. It depends on many factors, conditions, and limits. First, the salt or salts involved must be specified. Second, the conditions in which the crop is growing, which cause tolerance to vary greatly, must be specified. Third, the age and variety of a plant, which also affects the plant's tolerance, must be specified. To be useful to the farmer, salt tolerance must be defined in terms of the reduction in growth or yield caused by specified concentrations of salt. Of course, the factors mentioned also influence the degree of reduction in growth. Although a plant's capacity to endure salt cannot be stated in absolute terms, relative crop responses to known concentrations of salt under certain conditions can be predicted. This chapter focuses on crop tolerance and the various factors that affect it.

Salinity

When an ion exists in the soil solution at a concentration that exceeds the amount needed for optimum growth, it may become toxic to the plant. Different levels of ions have different toxic levels. Concentrations of chloride of up to 200 mol/m^3 or more may be tolerated by some plants (Maas 1986), while as little as 0.2 mol/m^3 of boron is toxic to some plants (Eaton 1944). Salinity, when used to refer to soil, denotes an excess of salts derived from alkali and alkaline earth metals, primarily Na^+, Ca^{2+}, and Mg^{2+}. The predominant anions are usually Cl^-, SO_4^{2-}, and HCO_3^-. A salt-affected soil is one that contains enough soluble salts to hamper growth of the crop. The proportion of Na^+ to Ca^{2+} and Mg^{2+} that soils contain further differentiate them, i.e., they are either saline, sodic, or saline-sodic. (See Chapter 5.) The relative concentrations of these ions can vary greatly among soils. Their effects on plants, particularly at extreme ratios, can also vary. Generally, however, plants respond similarly to salinity over a fairly wide range of combinations of salt. In this chapter, salt tolerance refers to the capacity of a crop to grow on a saline soil as defined in Chapter 5. Tolerance to specific ions or elements will be considered separately.

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Criteria for Salt Tolerance

The salt tolerance of a crop is appraised based on one of the following: its ability to survive on saline soils, the reductions in growth or reductions in yield at different levels of salinity, or its growth or yield when grown on saline soil compared to its growth or yield when grown on a nonsaline soil. Plant survival, an important ecological criterion, is of little value for evaluating tolerance at commercial production levels. The capability of plants to survive at extreme salinities often does not correlate with reductions in yield found at more moderate salinities. Actual yield responses to salinity are perhaps the most useful to a farmer, but differences in yield may be caused by different environmental factors, e.g., soil moisture, soil fertility, insects, and plant diseases. Furthermore, it is difficult to compare crops, since yields of different crops are not expressed in comparable units. To overcome this problem, yields can be expressed on a relative basis. Relative yield is the yield of a crop grown under saline conditions expressed as a fraction of that achieved under nonsaline, but otherwise comparable, conditions.

Source of Salt-Tolerance Data

Earlier publications on this subject were updated to compile the data on crop tolerances to salinity and specific ions and elements presented in this chapter (Maas and Hoffman 1977, Maas 1987). Generally, only those papers reporting on both the salinity of the root zone and the yield of the crop were used. In the case of some tree and vine crops, only the responses of vegetative growth were available. Data on ornamentals are based on salt injury and appearance, rather than plant growth. The literature covered in this review can be found in a bibliography compiled by Francois and Maas (1978, 1985).

ENVIRONMENTAL AND EDAPHIC FACTORS INFLUENCING SALT TOLERANCE

A plant's ability to tolerate salinity or specific ions is a function of many other conditions. The reliability of salt-tolerance data depends on whether the interaction between salinity and various conditions of soil, water, and climate influence yield reduction. Other environmental stresses may limit the yield, but they increase, decrease, or leave unaffected the crop's salt tolerance. Therefore, the effects of any interacting factor must be compared based on relative crop yield. Fig. 13.1 shows the types of interactions that illustrate this point. If the response to salinity is proportionately the same when a factor is limiting as when it is adequate, i.e., the absolute yields in both cases are decreased by the same percentage, the relative tolerance would be the same (Type A). If salinity decreases yields by the same absolute amounts for adequate and limiting conditions, a crop may appear relatively less tolerant under the suboptimal condition (Type B). However, if yield is severely limited by some suboptimal condition, e.g., inadequate soil fertility, a c may appear relatively more tolerant than if it were grown with uate fertility (Type C) because the effects of salinity on absolute yield cannot levels of soil salinity that begin to reduce yield and how much yield will be reduced at levels above the threshold. However, more precise plant response functions would be advantageous for crop simulation modeling. Several nonlinear models that more accurately describe the sigmoidal growth response of plants to salinity exist (van Genuchten and Hoffman 1984). The computer programs for these models were developed and documented by van Genuchten (1983). One of these models takes the form:

$$Y_r = \frac{Y_m}{\left[1 + \left(\frac{c}{c_{50}}\right)^p\right]} \tag{13.5}$$

where Y_m = the yield under nonsaline conditions; c = the average salinity of the root zone; c_{50} = the average salinity of the root zone that reduces yield by 50%; and p = an empirical constant. Values for the root zone's salinity, c and c_{50}, can be expressed in terms of either EC_e or OP_{fc}. Like the two-piece linear model, this sigmoidal model requires two parameters to describe the response curve, the values of c_{50} and p.

Salt Tolerances of Herbaceous Crops

Table 13.1 lists values for the threshold and slope of 69 crops in terms of EC_e. Most of the data were obtained from crops grown under conditions that simulated recommended cultural and management practices for commercial production. They show the relative tolerances of different crops grown under different non-standardized conditions. The data apply only where crops are exposed to fairly uniform salinities from the late seedling stage to maturity. Where crops have particularly sensitive stages, limits of tolerance are given in the footnotes.

The data in Table 13.1 apply to soils where chloride is the predominant anion. Since $CaSO_4$ is dissolved in preparing saturated-soil extracts, the EC_e of gypsiferous soils will range from 1 to 3 dS/m higher than that of non-gypsiferous soils with the same soil water conductivity at field capacity (Bernstein 1962). Therefore, plants grown on gypsiferous soils will tolerate an EC_e of approximately 2 dS/m higher than those listed in Table 13.1. The last column provides a qualitative rating of salt tolerance that can be used to categorize crops. Figure 13.3 illustrates the limits of these categories. Some crops are listed with only a qualitative rating because insufficient data are available to calculate the threshold and the slope.

Salt Tolerance of Woody Crops

Determining the salt tolerance of trees, vines, and other woody crops is complicated, since specific ion toxicities cause additional detrimental effects. The leaves of many perennial woody species are susceptible to injury by the toxic accumulation of Cl^-, or Na^+, or both, in the leaves. Different cultivars and rootstocks absorb Cl^- and Na^+ at different rates, so tolerance can vary considerably within a species. Tolerances to these specific ions will be discussed below. In the absence of specific-ion effects, the tolerance of woody crops can be expressed similarly to the tolerance of herbaceous crops, i.e., as a function of the concentration

TABLE 13.1a Salt Tolerance of Herbaceous Crops.[a]—Fiber, Grain and Special Crops

Crop		Electrical conductivity of saturated-soil extract			
Common name (1)	Botanical name[b] (2)	Threshold[c] dS/m (3)	Slope % per dS/m (4)	Rating[d] (5)	References (6)
Barley[e]	*Hordeum vulgare*	8.0	5.0	T	Maas and Hoffman (1977)
Bean	*Phaseolus vulgaris*	1.0	19.0	S	Maas and Hoffman (1977)
Broad bean	*Vicia faba*	1.6	9.6	MS	Maas and Hoffman (1977)
Corn[f]	*Zea Mays*	1.7	12.0	MS	Maas and Hoffman (1977)
Cotton	*Gossypium hirsutum*	7.7	5.2	T	Maas and Hoffman (1977)
Cowpea	*Vigna unguiculata*	4.9	12.0	MT	West and Francois (1982)
Flax	*Linum usitatissimum*	1.7	12.0	MS	Maas and Hoffman (1977)
Guar	*Cyamopsis tetragonoloba*	8.8	17.0	T	Francois et al. (1989b)
Kenaf	*Hibiscus cannabinus*			MT	Francois (1988c)
Millet, foxtail	*Setaria italica*			MS	Maas and Hoffman (1977)
Oats	*Avena sativa*			MT*	
Peanut	*Arachis hypogaea*	3.2	29.0	MS	Maas and Hoffman (1977)
Rice, paddy	*Oryza sativa*	3.0[g]	12.0[g]	S	Maas and Hoffman (1977)
Rye	*Secale cereale*	11.4	10.8	T	Francois et al. (1989a)
Safflower	*Carthamus tinctorius*			MT	Maas and Hoffman (1977)
Sesame[j]	*Sesamum indicum*			S	Yousif et al. (1972)
Sorghum	*Sorghum bicolor*	6.8	16.0	MT	Francois et al. (1984)
Soybean	*Glycine max*	5.0	20.0	MT	Maas and Hoffman (1977)

(continued)

Attachment 16

Natural Resources Consulting Engineers, Inc. (NRCE) (2002). "Assessment of Imperial Irrigation District's Water Use."

NRCE®

ASSESSMENT OF IMPERIAL IRRIGATION DISTRICT'S WATER USE

NATURAL RESOURCES CONSULTING ENGINEERS, INC.

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March 2002

I. INTRODUCTION

Imperial Irrigation District (IID) is a large irrigation district located in the Imperial Valley of Southern California, near the Colorado River and the Arizona border. IID is in charge of ordering and distributing approximately 3.2 million acre-feet of water from the Colorado River every year. IID's irrigation system is large and complex and includes the 82-mile All American Canal (AAC) as well as almost 1,700 miles of other canals, numerous reservoirs, over 1,400 miles of drain ditches, and almost 33,600 miles of tile drains.

The primary objective of this study by Natural Resources Consulting Engineers, Inc. (NRCE) was to evaluate the overall agricultural water uses within IID and determine whether such water uses are reasonable and beneficial. In addition, NRCE evaluated whether the proposed transfer by IID of up to 200,000 acre-feet per year of conserved water to the San Diego County Water Authority (SDCWA) would have an adverse impact on junior water right holders on the Lower Colorado River.

NRCE conducted a detailed analysis of IID's water supply, demand, delivery systems and irrigation, using records from 1988 to 1997 as well as a comparative water use study of several irrigation districts located within the Southwest and the Lower Colorado River Basin. NRCE also conducted its own field evaluation in the summer of 2000.

NRCE has concluded that IID's agricultural water uses are reasonable and beneficial. Despite its unique environmental conditions, IID has one of the highest on-farm irrigation efficiencies relative to the other irrigation districts served by the Lower Colorado River, and has a higher on-farm irrigation efficiency than the assumed expected efficiency by the State of California for the year 2020. According to a United States Bureau of Reclamation (USBR) study conducted in the late 70s, the on-farm irrigation efficiencies for the various irrigation districts in the Lower Colorado Basin ranged from 32 to 78%, and IID had the highest average on-farm efficiency of 78%. NRCE also determined that IID's proposed diversion of 200,000 acre-feet of conserved Colorado River water would have no meaningful adverse impact on other water right holders downstream of the proposed Lake Havasu diversion.

In evaluating IID's water use, NRCE considered the available water supply, water quality, and the major facilities that convey and distribute irrigation water to IID. In addition, NRCE analyzed the water requirements for the various crops grown in the District, taking into account the climate and the agricultural land resources of IID, and IID's delivery system.

IID's water use was first analyzed by NRCE using the water balance method. A volume balance analysis was performed for the entire District as a system-wide unit, as well as two subsystems that include the conveyance and distribution level subsystem and the on-farm level subsystem. The primary objective in the water balance method approach is to estimate the total water consumptive use. This method is appropriate for the Imperial Valley because of the Valley's unique physical setting and hydrogeologic conditions as a closed basin.

Determination of the on-farm and overall irrigation system efficiencies required examination of irrigation water beneficially used. There are various uses of irrigation water that are beneficial in addition to directly satisfying crop water demands. In IID, other beneficial uses of irrigation water include seedbed and land preparation, germination, cooling, and leaching for salinity control.

After completing its study, NRCE determined the following:

- During the study period (1988-1997), IID's on-farm efficiency averaged 83%, while its overall efficiency was about 74%. In other words 83% of the delivered water to the headgates was used for crop evapotranspiration (ET), leaching, and other crop production uses. The California Department of Water Resources (CDWR) assumes that statewide on-farm irrigation efficiency will be 73% by the year 2020 and could reach 80% through better irrigation management and improved facilities (CDWR 1998). The irrigation efficiency of IID has thus already surpassed the State's future efficiency estimate, 20 years ahead of time. To attain such irrigation efficiency, IID growers often apply lower amounts of water than they really need, thus limiting tailwater, but also accepting lower yields.

- The irrigation efficiency of IID is so high that even those irrigation projects that are served with some of the most technologically advanced irrigation systems, including drip irrigation, exhibit about the same level of irrigation efficiency. To the extent that water loss occurs, it is generally justified as a corollary to farming in a hot climate with heavy cracking soils.

- Based on the data assembled for NRCE's water budget study, IID's conveyance and distribution efficiency was determined by dividing the irrigation water delivered to the farms by the net supply of irrigation water to all the canals off the AAC. The average conveyance and distribution efficiency from 1988 to 1997 was determined to be approximately 89%. In other words, about 11% of the water diverted from the AAC was lost to evaporation and unrecovered seepage and spills before the irrigation water reached the farm headgates. The 89% conveyance efficiency is high, especially given the size of IID's irrigation project and the complexities of its water distribution system management.

- Tailwater is a vital and necessary component of the Imperial Valley's irrigation practice. Due to the low permeability of the heavy cracking soils in IID, it is difficult to adequately leach salts from the soil during regular irrigation applications. The nature of most of IID's soils requires more leaching water than stated in traditional formulae, of which the equations are more applicable to non-cracking heavy soils. Though both horizontal and vertical leaching occur during regular irrigation, only about 52% of the salts in the soil are leached at such time, while the other 48% remain in the root zone, requiring additional leaching between crops.

- During regular irrigation on IID's medium and heavy soils, only 4.5% of the applied water drains vertically, removing about 30% of the salt introduced by the irrigation water, while about 17% of the applied water ends up as tailwater that removes approximately 22% of the salt introduced by the irrigation water. This leaching process is compounded by the fact that the Colorado River, by the time it reaches IID, contains significantly increased mineral salt concentrations. Excess salts in light soils are more easily removed than salts in heavy cracking soils, such as those found in IID, because the permeability of the light soils is adequate for vertical leaching.

- On many IID farms with medium and heavy cracking soils, it would be best for growers to apply even more water during irrigation for leaching and crop consumptive use purposes than they currently do, because this would increase crop yields. However, since higher water application could result in higher tailwater, growers tend to apply barely enough water for crop use and for partial leaching of salts. As a result of insufficient leaching, the lower end of the field becomes too saline for crop production, thus decreasing the productivity of valuable acreage.

- When irrigation water is applied at the head of the field, it picks up salts from the soil as it moves to the lower end of the field. It was determined that the salinity of the tailwater is about 30% higher than the water delivered at the head of the field, which indicates significant horizontal leaching is taking place in IID because of the nature of its soils.

- Considering the three processes of leaching for cracking soils (vertical leaching during crop irrigation, leaching irrigation, and horizontal tailwater leaching), it was determined that approximately 0.73 acre-feet per acre is used for leaching on an annual basis. The leaching requirement for light soils was estimated to be about 0.58 acre-feet per acre per year. About 87% of IID irrigated lands have limited permeability in the root zone, while the remaining 13% are light soils.

Based on the above results and the other matters addressed in this report, it is NRCE's opinion that the overall irrigation water use in IID is reasonable and beneficial. Though IID has been criticized by some for its water use, in NRCE's opinion such criticisms are uninformed and unjustified. A reasonable look at IID's water usage shows that IID and its growers manage reasonably well in difficult environmental circumstances, and in fact could justify using more water for leaching and crop consumptive use than they currently utilize.

Attachment 17

U.S Bureau of Reclamation (BOR). (1989-1997). Compilation of Records in Accordance with Article V of the Decree of the Supreme Court of the United States in Arizona v. California, March 9th, 1964.

COMPILATION OF RECORDS IN ACCORDANCE WITH ARTICLE V OF THE DECREE OF THE SUPREME COURT OF THE UNITED STATES IN ARIZONA v. CALIFORNIA DATED MARCH 9, 1964

CALENDAR YEAR 1997

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Bureau of Reclamation

Boulder Canyon Operations Office
Lower Colorado Region
Boulder City, Nevada

The following tabulations for calendar year 1997 show final records of diversions of water from the mainstream of the Colorado River, return flow of such water to the mainstream and consumptive use of such water. The records were furnished by the U.S. Geological Survey, International Boundary and Water Commission, Bureau of Indian Affairs, Bureau of Reclamation (Reclamation), National Park Service, U.S. Fish and Wildlife Service, and water user agencies. Diversions from the All-American Canal and Gila Gravity Main Canal at Imperial Dam were assigned to each user by adding each user's proportional share of the total canal losses to the delivery taken by each user at its turnout from the canal.

The tabulations also show quantities of water pumped from the mainstream or from wells in the Colorado River flood plain. Amounts diverted by pumping were determined by one of two methods: (1) For most electric pumps, diversions were computed on a monthly basis from power records and a "kilowatthour per acre-foot factor" that was determined by discharge measurement; (2) For pumps other than electric and some electric pumps, a consumptive use factor of 6 acre-feet per irrigated acre per year was used.

Consumptive use estimates for individual diverters may be over or under estimated. Reclamation is continuing the development of the Lower Colorado River Accounting System to refine estimates of consumptive use.

Tabulations for calendar year 1997 do include acceptable determinations of the unmeasured Colorado River return flows to Lake Mead from Las Vegas Wash which accrue to the State of Nevada and a portion of the unmeasured return flows from the Yuma Mesa which are credited to the State of Arizona.

No person or entity is entitled to divert or use Colorado River water without an entitlement. An entitlement is an authorization to beneficially use Colorado River water pursuant to: (1) a right decreed by the Supreme Court, (2) a contract with the United States through the Secretary of the Interior (Secretary), or (3) a Secretarial reservation of water. The recording of diversions, return flows, or consumptive use in this tabulation is for statistical use only and is not to be interpreted as an entitlement, indication that the use is authorized, or imply that return flow credits are associated with a specific entitlement.

DIVERSIONS FROM MAINSTREAM-AVAILABLE RETURN FLOW
AND CONSUMPTIVE USE OF SUCH WATER
CALENDAR YEAR 1997
STATE OF ARIZONA

01/13/99

(ACRE-FEET)

WATER USER		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL 1/
TOWN OF PARKER														
PUMPED FROM RIVER	DIVERSION	0	0	0	0	0	0	0	0	0	0	0	0	0
1 WELL-NW NW NW SEC 7 T9N R19W G&SRM	DIVERSION 10/	49	52	77	84	84	108	113	106	84	172	54	47	1031
	RETURNS	0	0	0	0	0	0	0	0	0	0	0	0	0
	CONSUMPTIVE USE	49	52	77	84	84	108	113	106	84	172	54	47	1031
COLORADO RIVER INDIAN RESERVATION														
DIVERSION AT HEADGATE ROCK DAM	DIVERSION	7720	42700	55570	59260	75820	76440	81880	73480	50230	38460	28580	26240	616380
1 PUMP FROM RIVER (B-04-22)14 bbd	DIVERSION 3/10/	1077	555	879	1069	1568	2058	1995	2320	2082	942	259	472	15278
	RETURNS	12526	13878	18613	20167	21886	23095	23926	24894	22626	19955	18429	18940	238935
	CONSUMPTIVE USE	-3729	29377	37836	40162	55502	55403	59949	50906	29686	19447	10410	7772	392723
EHRENBURG IMPROVEMENT ASSN.														
1 PUMP SW SEC 3 T3N R22W G&SRM	DIVERSION	29	28	37	38	41	51	58	57	47	36	46	31	499
	RETURNS													
	CONSUMPTIVE USE													
CIBOLA VALLEY IRRIGATION DISTRICT														
5 PUMPS SEC'S 20, 21 & 26T1N R23W	DIVERSION	411	3001	1671	2823	4005	4470	5059	4535	2137	1275	714	782	30883
	RETURNS													
	CONSUMPTIVE USE													
CIBOLA NATIONAL WILDLIFE REFUGE														
4 PUMPS, SEC 2 AND 31	DIVERSION	625	327	563	1384	1085	1827	1798	1778	1735	1555	1583	814	15075
	RETURNS													
	CONSUMPTIVE USE													
IMPERIAL NATIONAL WILDLIFE REFUGE														
2 WELLS SEC 13 T5S R22W G&SRM	DIVERSION 2/	426	342	582	629	769	932	1017	978	769	644	458	450	8000
	RETURNS													
	CONSUMPTIVE USE													
YUMA PROVING GROUND														
DIVERSION AT IMPERIAL DAM	DIVERSION	0	0	0	0	2	0	0	0	0	0	0	0	2
WELLS X,Y,M	DIVERSION	27	30	87	122	126	151	167	145	88	30	36	28	1037
	RETURNS	0	0	0	0	0	0	0	0	0	0	0	0	0
	CONSUMPTIVE USE	27	30	87	122	128	151	167	145	88	30	36	28	1039
STURGES														
DIVERSION AT IMPERIAL DAM	DIVERSION	220	424	601	719	844	739	712	1137	748	591	789	480	8004
	RETURNS	-4	9	15	-21	-16	40	-49	-45	55	-8	28	39	43
	CONSUMPTIVE USE	224	415	586	740	860	699	761	1182	693	599	761	441	7961
WELLTON MOHAWK I. & D. DISTRICT														
DIVERSION AT IMPERIAL DAM	DIVERSION	16499	27704	37383	38564	52362	55104	48976	39040	31655	28997	23236	15670	415190
	GGMC RETURN	-352	625	1060	-1240	-1088	3334	-3818	-1756	2614	-468	920	1400	1231
	DOME RETURN	1105	1013	1176	632	562	228	305	180	513	1121	1240	1670	9745
	MOD RETURN 9/	6460	7900	8980	8320	10750	10550	7770	6090	5770	6500	6310	6300	91700
	RETURNS, TOTAL	7213	9538	11216	7712	10224	14112	4257	4514	8897	7153	8470	9370	102676
	CONSUMPTIVE USE	9286	18166	26167	30852	42138	40992	44719	34526	22758	21844	14766	6300	312514
CITY OF YUMA														
DIVERSION AT IMPERIAL DAM (AAC)	DIVERSION	1814	1691	2091	1990	2606	2669	2836	3061	2465	2787	2072	1968	28050
DIVERSION AT IMPERIAL DAM (GILA)	DIVERSION	0	0	0	0	0	0	0	0	0	0	0	0	0
	RETURNS	811	723	801	728	777	818	908	921	1058	1425	1002	1109	11081
	CONSUMPTIVE USE	1003	968	1290	1262	1829	1851	1928	2140	1407	1362	1070	859	16969
MARINE CORPS AIR STATION (YUMA)														
DIVERSION AT IMPERIAL DAM	DIVERSION	84	100	162	185	239	256	287	277	218	155	102	58	2123
	RETURNS													
	CONSUMPTIVE USE													

Attachment 18

U.S. Bureau of Reclamation (BOR). (1989-1997). Crop Production and Water Utilization Data.

7-2045 (2-9 1)
Bureau of Reclamation

OMB Approval No. 1006-0001
Expires 12-31-93

CROP PRODUCTION AND WATER UTILIZATION DATA FOR 19 98

SHEET 1 OF 5

ADP Code (I-6)	Project & Subdivision	State	Region
30470	Wellton Mohawk Irrigation and Drainage District	AZ	LC

TYPE OF IRRIGATION SERVICE (7) ☒ Full ☐ Supplemental ☐ Temporary

1st compl

RECEIVED APR 1998

2nd corre

RECEIVED JAN 1999

PART A — ACREAGE SUMMARY

LINE CODE (10-12)	LANDS IN IRRIGATION ROTATION (Acres)	CLASS 1-4 (13-21)	CLASS 5 (22-30)	TOTAL (31-40)
11	Harvested cropland and pasture (from Line 194)	57,894		
12	Cropland not harvested and soil building	306		
13	Acres irrigated (Lines 11 + 12)	58,200		
14	Fallow or idle	1,731		
15	Total Area in Irrigation Rotation (Cultivation) (Lines 13 + 14)	59,931		
	LANDS NOT IN IRRIGATION ROTATION (Acres)			
16	Dry cropped, idle, fallow, or grazed	13		
17	Farmsteads, roads, ditches, drains	2,239		
18	Total Area Not in Irrigation Rotation (Lines 16 + 17)	2,252		
19	URBAN AND SUBURBAN LANDS	263		
20	TOTAL IRRIGABLE AREA FOR SERVICE (Lines 15 + 18 + 19)	62,446		
21	TOTAL IRRIGABLE AREA NOT FOR SERVICE	298		
22	TOTAL IRRIGABLE AREA (Lines 20 + 21)	62,744		
23	CLASS 6 - TEMPORARILY IRRIGATED			

PART B — CROP VALUE SUMMARY

LINE CODE		(22-30)	
31	GROSS CROP VALUE (from Line 194)		
32	ADDITIONAL REVENUE:		
33	Federal ASCS Payments		
34	Sugar Program:		
35	Total Additional Revenue (Lines 33 + 34)		
36	TOTAL VALUE (Gross crop value plus additional revenue - (Lines 31 + 35)		
37	TOTAL IRRIGATED ACREAGE (from Line 13)		
38	AVERAGE VALUE PER IRRIGATED ACRE (Line 36 / Line 37)		

PART C — NUMBER OF FARMS AND POPULATION

LINE CODE		NO. OF FARMS (OPERATING UNITS) (13-21)	IRRIGABLE ACRES FOR SERVICE (22-30)	POPULATION (31-40)
41	FULL TIME FARMS	108	60,796	324
42	PART TIME FARMS	24	1,387	72
43	URBAN AND SUBURBAN LANDS (acres from Line 19)		263	531
44	TOTAL (acres from Line 20)		62,446	

This information is collected to effectively administer, manage and evaluate the Federal Reclamation Program. Data are used for economic analysis, program evaluation, and to respond to congressional and other inquiries. Response to this request is required to obtain a benefit in accordance with Public Law 76-260. Public reporting burden for this information collection is estimated to average .33 hours per response, including time for reviewing instructions, gathering and maintaining data, and completing and reviewing the form. Direct comments regarding the burden estimate or any other aspect of this form to Chief, Publications and Records Management Branch, Code D-7920, Bureau of Reclamation, Denver Federal Center, PO Box 25007, Denver, CO 80225-0007; and the Office of Management and Budget, Paperwork Reduction Project 1006-0001, Washington, DC 20503

7-2045 (2-9 1)
Bureau of Reclamation

CROP PRODUCTION AND WATER UTILIZATION DATA FOR 1998

SHEET 2 OF 5

ADP Code (1-6)	Project & Subdivision	State	Region
304700	Wellton Mohawk Irrigation and Drainage District	AZ	LC

TYPE OF IRRIGATION SERVICE (7) ☒ Full ☐ Supplemental ☐ Temporary

PART D

CROP PRODUCTION

	LINE CODE	CROPS HARVESTED IN IRRIGATION ROTATION	ACRES	UNIT	YIELD PER ACRE	YIELD TOTAL	VALUE OF CROPS PER UNIT	VALUE OF CROPS PER ACRE	VALUE OF CROPS TOTAL
	(10-12)		(13-21)		(22-30)	(31-40)	(41-48)	(49-57)	(58-66)
CEREALS	51	Barley HIGH YIELD BUT CORRECT	62	Bu.	104.79	6,497	3.00	314.37	19,491
	52	Corn HIGH YIELD BUT CORRECT	1,570	Bu.	193.41	303,654	2.86	553.15	868,450
	53	Oats		Bu.					
	54	Rice		Cwt.					
	56	Sorghums (sorgo, Kaffir, etc)	154	Bu.	45.45	6,999	2.80	127.26	19,597
	57	Wheat HIGH YIELD BUT CORRECT	13,702	Bu.	116.10	1,590,802	2.77	321.60	4,406,522
	58	Other Cereals		Cwt.					
	59	TOTAL CEREALS	15,488					343.11	5,314,060
FORAGE	61	Alfalfa hay	15,501	Ton	9.06	140,439	90.00	815.40	12,639,510
	62	Other hay	6,073	Ton	5.07	30,790	76.51	387.91	2,355,743
	63	Irrigated pasture		AUM					
	65	Silage or Ensilage		Ton					
	66	Crop residue: Beet tops		Ton					
	67	Stubble, stalks, etc.		AUM					
	68	Straw (all kinds)		Ton		1,191	50.00		59,550
	70	Other forage		Ton					
	71	TOTAL FORAGE	21,574					697.82	15,054,803
MISC FIELD CROPS	81	Beans, dry and edible		Cwt.					
	82	Cotton, lint (Upland)	15,191	Bale	2.09	31,749	350.00	731.50	11,112,150
	83	Cotton, seed (Upland)		Ton	0.83	12,609	147.00	122.01	1,853,523
	84	Cotton, lint (Am-Pima)	37	Bale	1.40	52	500.00	700.00	26000
	85	Cotton, seed (Am-Pima)		Ton	0.55	20	147.00	80.85	2940
	86	Hops		Ton					
	87	Peppermint		Lb.					
	88	Spearmint		Lb.					
	89	Sugar Beets		Ton					
	90	Soybeans		Bu.					
	91	Other miscellaneous field crops	822	Ton	0.94	773	1,208.85	1,136.32	934441
	92	TOTAL MISCELLANEOUS FIELD CROPS	16,05[illegible]						[illegible]3,929,054

Attachment 19

U. S. Bureau of Reclamation (BOR). (1995). "Lower Colorado River Accounting System, Demonstration of Technology."

Lower Colorado River Accounting System

Demonstration of Technology

Documentation for Calendar Year 1995

Attachment 20

U.S. Bureau of Reclamation (BOR). (1981). Water and Power Resources Service Project Data.

Water and Power Resources Service

[illegible]

A Water Resources Technical Publication

UNITED STATES DEPARTMENT OF THE INTERIOR

WATER AND POWER RESOURCES SERVICE

CONTENTS

PAGE

PROJECT

Contents

Attachment 21

U.S. Department of Agriculture, Soil Conservation Service. (1967). "Irrigation Water Requirements Technical Release No. 21." Revised 1970.

IRRIGATION WATER REQUIREMENTS

TECHNICAL RELEASE No 21

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION

APRIL 1967

REVISED SEPTEMBER 1970

U. S. Department of Agriculture
Soil Conservation Service
Engineering Division

Technical Release No. 21 (Rev. 2)
September, 1970

IRRIGATION WATER REQUIREMENTS

Introduction

It is essential that the water requirements and consumptive use of water be known in irrigation planning for soil conservation and irrigation districts and for individual farms. Conservation of water supplies, as well as of soils, is of first importance in the agricultural economy. In basin-wide investigations of water utilization and in water conservation surveys, consumptive water requirement is one of the most important factors to be considered. There is an urgent need for information on irrigation requirements in connection with farm planning programs for areas where few data are available.

A knowledge of consumptive use is necessary in planning farm irrigation system layouts and improving irrigation practices. Irrigation and consumptive water requirement data are used more and more widely by water superintendents as well as state, federal, and other agencies responsible for the planning, construction, operation and maintenance of multiple-purpose projects and by those responsible for guiding and assisting farmers in the solution of their irrigation problems.

Scope

This release covers the procedures used to estimate irrigation water requirements on a farm or on a project. Irrigation application efficiencies are discussed briefly. More detailed information is presented in applicable chapters of Section 15 of the National Engineering Handbook. Procedures for measuring losses in existing farm distribution and project conveyance systems and for estimating losses in such systems as may be proposed are included. Irrigation water storage requirements may be estimated by use of the procedure contained in Technical Release No. 19.

Definition of Terms

Some of the terms used in this release are defined as follows:

Consumptive Use.
Consumptive use, often called evapo-transpiration, is the amount of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil or

Attachment 22

U.S. Department of Agriculture, Soil Conservation Service. (1986). "Soil Survey of Colorado River Indian Reservation, Arizona-California."

Soil Survey of
Colorado River Indian Reservation Arizona—California

By Frank L. Nelson, Soil Conservation Service

Fieldwork by Frank L. Nelson and Edward R. Fenn,
Soil Conservation Service

United States Department of Agriculture, Soil Conservation Service
In cooperation with
United States Department of the Interior, Bureau of
Indian Affairs; Arizona Agricultural Experiment Station; and
California Agricultural Experiment Station

COLORADO RIVER INDIAN RESERVATION is in the southwestern part of Arizona and the southeastern part of California. It consists of parts of La Paz County, Arizona, and Riverside and San Bernardino Counties, California. The reservation was established on March 3, 1965. It has a total area of 268,850 acres, or 420 square miles. Parker, Arizona, the largest town in the survey area, has a population of 3,100, and Parker Valley has a population of about 9,800. Other communities on the reservation include Big River, California, and Poston, Arizona. About 2,600 Indians of the Mohave, Chemehuevi, Navajo, and Hopi tribes live on homesites scattered throughout the reservation.

The survey area is in the Western Range and Irrigated Region of the Sonoran Desert section of the Basin and Range province. The boundaries follow irregular lines. The Colorado River flows through the survey area. Elevation ranges from 250 feet where the Colorado River flows out of the area to 2,500 feet on some of the peaks scattered throughout the area.

The climate in the survey area is characterized by moderate weather in winter and by hot, dry weather in summer. Precipitation is sporadic. It occurs mainly in July to September and December to February.

Farming is the most important economic enterprise in the survey area. The main crops are cotton, alfalfa, lettuce, melons, grain sorghum, wheat, and onions. Additional income is provided by tourism.

About 99 percent of the farmland is on the flood plain of the Colorado River, where there is access to gravity-fed water from Headgate Rock Dam. The other 1 percent, or about 1,585 acres, is above the flood plain escarpment and on adjacent terraces and is irrigated by water from wells.

Arizona Highway 72 and California Highway 62 cross the northern part of the reservation, U.S. Highway 95 generally parallels the western side, and a good blacktop road called "Mohave Road" traverses the middle of Parker Valley from north to south. A railroad crosses the northern and eastern parts of the reservation. Parker is served by a busline and an airport, which handles local air traffic. Most of the major crossroads in the valley have been blacktopped, and a bridge that connects Mohave Road with U.S. Highway 95 has been rebuilt across the Colorado River.

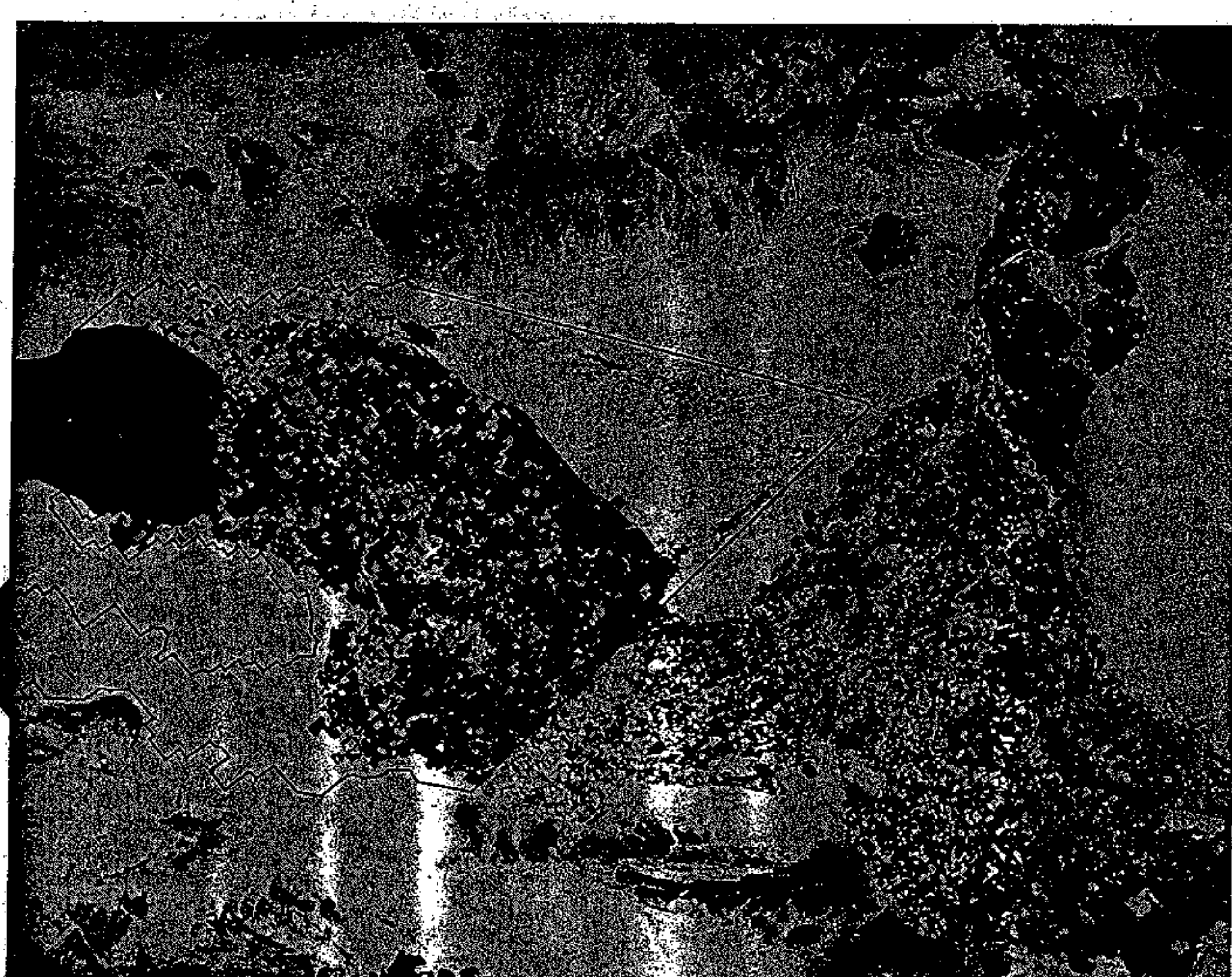
Descriptions, names, and delineations of soils in this soil survey do not fully agree with those on soil maps for adjacent survey areas. Differences are the result of better knowledge of soils, modifications in series concepts, intensity of mapping, or the extent of soils within the survey.

Attachment 23

U.S. Department of Agriculture, Soil Conservation Service. (1980). "Soil Survey of Imperial County, California, Imperial Valley Area."

Soil Survey of

IMPERIAL COUNTY CALIFORNIA IMPERIAL VALLEY AREA



United States Department of Agriculture Soil Conservation Service
in cooperation with
University of California Agricultural Experiment Station
and
Imperial Irrigation District

SOIL SURVEY OF IMPERIAL COUNTY, CALIFORNIA, IMPERIAL VALLEY AREA

By Robert P. Zimmerman, Soil Conservation Service

Field work by Robert P. Zimmerman, Jason W. Decker, Albert S. Endo, Forrest W. Flannagan, James W. Lockard, John McAllaster, Robert G. Pratt, Guy J. Romito, Soil Conservation Service; Gerald Mitchell, Major Mitchell, Imperial Irrigation District

United States Department of Agriculture, Soil Conservation Service in cooperation with the University of California Agricultural Experiment Station and the Imperial Irrigation District

The Imperial Valley is in the southern part of California (see map on facing page). The survey area is in the south-central part of Imperial County, and is bounded by Mexico on the south, the Algodones Sand Hills on the east, the Salton Sea on the north, San Diego County on the northwest, and the alluvial fans bordering the Coyote Mountains and the Yuha Desert on the southwest. Elevation ranges from 230 feet below sea level to about 350 feet above. El Centro is the county seat and largest city of Imperial County, with a population of about 20,000. The Imperial Valley Area encompasses 989,450 acres.

Soils here are formed in stratified alluvial materials and vary greatly in texture and thickness of layers. Many soils are affected by soluble salts, and drainage is a problem in the irrigated areas.

A favorable climate plus water diverted from the Colorado River have enabled Imperial County's agricultural production to rank among the highest in California. Over 20 crops, as well as livestock and apiary products, brought high returns in 1975.

The soils of the Imperial Valley Area were first studied and mapped in 1901 and 1903 (*10, 11*). These studies considered the problems of salinity control and drainage and the management of such problems. The soils were more intensively mapped in 1922 and 1923 (*12, 13*), and the soils of the Imperial East Mesa were examined in 1944 (*16*). The present survey has been prepared to provide the more detailed information required by a rapidly developing and expanding agricultural and land-use technology.

General nature of the area

This section provides general information about the Imperial Valley Area. It discusses physiography, relief, and drainage; history and development; natural resources; and climate.

Physiography, relief, and drainage

The physiography of the Imperial Valley is that of a great basin. It is part of the northern extension of the giant geologic trough occupied by the Gulf of California. The portion of the basin within the survey area is bounded on the east by the Chocolate and Cargo Muchacho Mountains and on the west by the Coyote and Fish Creek Mountains. The Imperial Valley is separated from the Gulf of California by the ridge of the Colorado River delta, which is about 30 feet above sea level at its lowest point. The lowest part of the basin is the bed of the prehistoric Lake Cahuilla, where the beach line is about 35 feet above sea level. The deepest part of the lakebed, now filled by the Salton Sea, is about 270 feet below sea level. The shoreline of the Salton Sea was about 230 feet below sea level in 1974.

The main irrigated areas of the Valley are on the lakebed floor between the international boundary on the south and the Salton Sea on the north. This area is nearly level, with a slope toward the Salton Sea of about 0.1 percent. From the east and west edges toward the center, the slope is about 0.3 percent. The fine- and moderately fine-textured lakebed sediments are the parent materials of the Glenbar, Holtville, and Imperial soils and the underlying layers of the Meloland and Niland soils (fig.1). Windblown and river channel silts and sands deposited in the lake basin are the sources of the Indio, Vint, and Rositas soils and the surface layer of the Meloland soils. Rositas and Carsitas soils were formed in the beach deposits. Four low volcanic hills rise about 100 feet above the lakebed along the southeast edge of the Salton Sea.

Between the east side of the old lake basin and the Algodones Sand Hills is a desert plain, the Imperial East Mesa, which is a terrace of the Colorado River delta. This area is nearly flat, but slopes to the west about 0.1 percent near the southern edge of the international boundary. The grade increases slightly in the north part

Attachment 24

U.S. Department of Agriculture. (1926). "Soil Survey of the Palo Verde Area, California."

U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF SOILS

IN COOPERATION WITH THE UNIVERSITY OF CALIFORNIA AGRICULTURAL EXPERIMENT STATION

SOIL SURVEY OF THE PALO VERDE AREA CALIFORNIA

BY

A. E. KOCHER, IN CHARGE, AND F. O. YOUNGS

[Advance Sheets—Field Operations of the Bureau of Soils, 1922]

WASHINGTON
GOVERNMENT PRINTING OFFICE
1926

ILLUSTRATIONS

PLATES

FIGURE

MAPS

SOIL SURVEY OF THE PALO VERDE AREA CALIFORNIA

By A. E. KOCHER, in Charge, and F. O. YOUNGS

DESCRIPTION OF THE AREA

The Palo Verde area is situated about 40 miles northeast of the Imperial Valley, near the extreme southeastern part of California. Blythe, the principal town, is about 200 miles east of Los Angeles. The area comprises the Palo Verde Valley lying along the Colorado River, the Palo Verde Mesa with a number of detached desert mountains, and a narrow strip along the east side of the Colorado Desert comprising a part of the Chuckawalla Valley. The greater part of the survey lies in the southeastern corner of Riverside County; a strip about 3 miles in width extends south into Imperial County. The Colorado River forms the east boundary and separates the area from the State of Arizona. The north boundary is formed principally by the Santa Maria Mountains, the south boundary by an east-and-west line extending through the foothills of the Palo Verde Mountains, and the west boundary is mainly a north-and-south line extending through Ironwood Mountain and thence south across the desert along the west side of the Mule and Palo Verde Mountains. The area is roughly rectangular and comprises 423 square miles, or 270,720 acres. Generally speaking, it consists of two divisions, the low, recent alluvial lands known as the Palo Verde Valley, elevation 240 to 275 feet above sea level, and the higher desert lands bordering the valley on the west. From the agricultural standpoint, the Palo Verde Valley is much the more important. It extends from the Blythe Intake on the north where the Santa Maria Mountains completely shut off the lowlands, southwestwardly a distance of 30 miles, where it is again pinched out by the encroaching foothills of the Palo Verde Mountains. The valley is crescent shaped and reaches a maximum width of about 10 miles between the towns of Blythe and Ripley. Except in a number of places where small areas are dotted with wind-blown mounds, 3 to 20 feet in height, the surface is generally smooth, with a uniform slope from north to south of about 1½ feet to the mile. The highest part of the valley is on the east side along the river, the

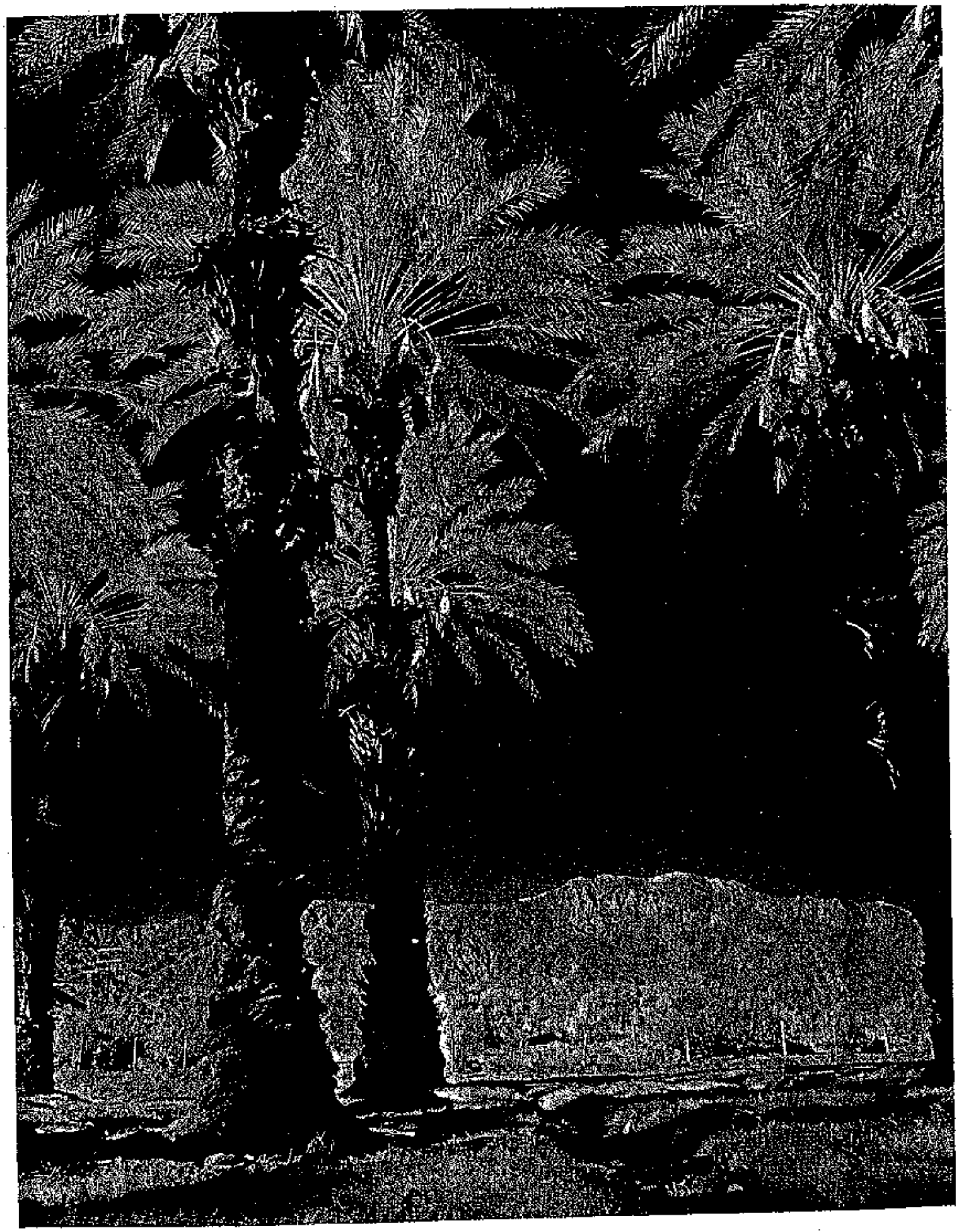
FIG. 17.—Sketch map showing location of the Palo Verde area, California

Attachment 25

U.S. Department of Agriculture, Soil Conservation Service. (1974). "Soil Survey of Riverside County, California, Coachella Valley Area."

SOIL SURVEY OF

Riverside County, California Coachella Valley Area



United States Department of Agriculture
Soil Conservation Service
in cooperation with
University of California Agricultural Experiment Station

SOIL SURVEY OF RIVERSIDE COUNTY, CALIFORNIA
COACHELLA VALLEY AREA

BY ARNOLD A. KNECHT

FIELDWORK BY ARNOLD A. KNECHT, CONRAD R. SIMONSON, AND EDDIE SPENCER, SOIL CONSERVATION SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE, IN COOPERATION WITH THE UNIVERSITY OF CALIFORNIA AGRICULTURAL EXPERIMENT STATION

THE COACHELLA VALLEY AREA, in the central part of Riverside County north of Salton Sea, extends from Imperial County to San Bernardino County (see facing page). The survey area is 560,640 acres in extent. It has a population of 106,000 (*6*).[1] Indio, the principal town, has a population of 14,361.

High value agricultural crops are grown extensively in the Coachella Valley Area. Large acreages are used for oranges, lemons, grapefruit, table grapes, and dates. Extensive acreages are in carrots, corn, tomatoes, onions, squash, bell peppers, radishes, and leaf lettuce for shipment to areas where such produce is out of season. Alfalfa and cotton are other important crops grown in rotation with the out-of-season crops. All crops are irrigated.

How This Survey Was Made

Soil scientists made this survey to learn what kinds of soil are in Coachella Valley Area, where they are located, and how they can be used. They went into the Area knowing they likely would find many soils they had already seen and perhaps some they had not. They observed steepness, length, and shape of slopes; kinds of crops and native plants; kinds of rock; and many facts about the soils. They dug many holes to expose soil profiles. A profile is the sequence of natural layers, or horizons, in a soil; it extends from the surface down into the parent material that has not been changed much by leaching or by the action of plant roots.

The soil scientists made comparisons among the profiles they studied, and they compared these profiles with those in areas nearby and in places more distant. They classified and named the soils ording to nationwide, uniform procedures. The series and the

or other geographic feature near the place where a soil of that series was first observed and mapped. Coachella and Indio, for example, are the names of two soil series. All the soils in the United States having the same series name are essentially alike in those characteristics that affect their behavior in the undisturbed landscape.

Soils of one series can differ in texture of the surface layer and in slope, stoniness, or some other characteristic that affects use of the soils by man. On the basis of such differences, a soil series is divided into phases. The name of the soil phase indicates a feature that affects management. For example, Coachella fine sand is one of the four phases within the Coachella series.

After a guide for classifying and naming the soils had been worked out, the soil scientists drew the boundaries of the individual soils on aerial photographs. The photographs show roads, buildings, field borders, trees, and other details that help in drawing boundaries accurately. The soil map at the back of this publication was prepared from aerial photographs.

The areas shown on a soil map are called mapping units. On most maps detailed enough to be useful in planning the management of farms and fields, a mapping unit is nearly equivalent to a soil phase. It is not exactly equivalent, because it is not practical to show on such a map all the small, scattered bits of soil of some other kind that have been seen within an area that is dominantly of a recognized soil phase.

Some mapping units are made up of soils of different series, soils of one series and a land type, or a broadly mapped soil (subgroup or great group) and a land type. Six such mapping units are shown on the maps of the Coachella Area—all soil complexes.

A soil complex consists of areas of two or e soils, or soils and land types, so intermingled or small in

Attachment 26

U.S. Department of Agriculture, Soil Conservation Service. (1980). "Soil Survey of Yuma-Wellton Area."

SOIL SURVEY OF YUMA-WELLTON AREA
PARTS OF YUMA COUNTY, ARIZONA, and IMPERIAL COUNTY, CALIFORNIA

By Russel L. Barmore, Soil Conservation Service

Soils surveyed by Russel L. Barmore, Earl G. Chamberlin, Harlan E. Jacoby, and John P. White, Soil Conservation Service

United States Department of Agriculture, Soil Conservation Service, in cooperation with the Arizona Agricultural Experiment Station and the California Agricultural Experiment Station

YUMA-WELLTON AREA, PARTS OF YUMA COUNTY, ARIZONA, AND IMPERIAL COUNTY, CALIFORNIA, (referred to elsewhere in this survey as Yuma-Wellton Area) is in the southwest corner of Arizona and the southeast corner of California. It has a total area of 1,042,429 acres, or 1,628 square miles. Yuma, the county seat of Yuma County, has a population of 35,000.

The survey area is in the Western Range and Irrigated Region of the Sonoran Desert section of the Basin and Range province. The Colorado River and the All-American Canal form the western boundary. The Gila River is an intermittent stream that flows westerly through the central part of the area. The northern and southern parts consist of old river terraces and broad alluvial fans that are drained by the Gila and Colorado Rivers.

Elevation ranges from 75 feet where the Colorado River enters Mexico to more than 2,000 feet on some of the peaks scattered throughout the survey area.

The climate in the survey area is characterized by moderate temperatures in winter and by hot, dry weather in summer. Precipitation is sporadic. It occurs mainly in the period of July to December.

Farming is the most important industry in the survey area. The main crops are citrus fruit, cotton, alfalfa, small grain, and truck crops. Additional income is provided by military installations and tourism.

General nature of the area

This section briefly discusses the settlement and development, history of irrigated farming, farming, transportation, and climate of the survey area.

Settlement and development

The survey area is rich in cultural history. Hernando de Alarcon, an early Spanish explorer, sailed up the Colorado River past the present site of Yuma in 1540. At that time Indians of the Yuman culture were living along the banks of the Colorado and Gila Rivers.

During the period of the American Revolution, Padre Francisco Garces established two missions in the area. The area south of the Gila River remained in Mexican hands until completion of the Gadsden Purchase in 1854.

In the early days it was impossible for wagon trains to traverse the rugged terrain north of the Gila River. Many immigrants to the California goldfields thus followed the Gila Trail, which crossed the Colorado River where Yuma now stands. By 1875 a number of homesteads had been established in both the Mohawk and Antelope Valleys to the east. Most of the early settlers were probably either miners or persons who worked at the river crossing. The Pony Express and Butterfield-Overland Stage Line did much to encourage settlement. With the extension of the Southern Pacific Railroad into the area in 1877, the area was opened up for development.

The city of Yuma was surveyed by Charles D. Poston, one of Arizona's first legislators, in 1854. By 1880 the population was 1,200, second only to Tucson in the Arizona territory. When Arizona became a state in 1912, Yuma had a population of 6,000. The survey area now has a population of 43,000. Yuma has been experiencing a rapid increase in population since 1960.

Farming is the leading economic enterprise in the area, although government employment and winter visitors contribute significantly to the economy.

History of irrigated farming

Early farmers in the survey area had to rely mainly on the annual spring floods of the Colorado River to provide moisture for crops. When the floods failed, the Indians subsisted on wild plants such as mesquite, Indian tea, and several varieties of cactus. Hernando de Alarcon observed Indians carrying on a form of irrigated farming at the confluence of the Gila and Colorado Rivers, a few

Attachment 27

U. S. Geological Survey. (1989-1997). "Salinity and Stream Gage Records, Lee's Ferry, Below Parker Dam and Above Imperial Dam."

EC and Instantaneous Flow Data. Annual Average Values					Partially missing data	
	Lee's Ferry		Below Parker Dam		Above Imperial dam	
Year	9380000 (mmhos)	9380000 (cfs)	9427520 (mmhos)	9427520 (cfs)	9429490 (mmhos)	9429490 (cfs)
1922		22481				
1923		22428				
1924		17166				
1925		15625				
1926		19305				
1927		22847				
1928		21085				
1929		26504				
1930		18028				
1931		8807				
1932		21006				
1933		13438				
1934		6046				9,624
1935		13667		8,960		6,630
1936		16440		8,213		7,229
1937		16397		7,965		7,065
1938		21292		8,158		7,360
1939		12929		10,825		9,990
1940		9719		9,945		9,184
1941		22135		16,261		15,275
1942	1,635	23495		24,099		23,457
1943	1,148	15,765		16,119		14,750
1944	1,204	17,932		19,038		18,230
1945	1,175	16,255		17,103		14,500
1946		12,087		15,053		14,040
1947	1,231	19,403		14,303		13,420
1948	1,176	17,747		17,040		14,180
1949	1,180	20,173		17,604		16,940
1950	1,189	14,917		16,629		15,860
1951	1,195	13,676		11,702		30,750
1952	1,153	24,663		18,786		11,810
1953	1,270	12,058		17,352		10,840
1954	1,293	8,515		13,168		10,300
1955	1,346	9,623		12,348		11,600
1956	1,161	11,927		9,520		8,710
1957	1,230	25,833		9,397		8,875
1958	1,095	18,150		15,462		14,780
1959	1,211	9,752		12,179		11,390
1960	1,153	12,108		10,937		10,110
1961	1,258	10,104		10,015		9,016
1962	1,190	19,944		9,531		8,581
1963	1,302	1,911		10,198		9,102
1964	1,126	4,468		9,348		8,530
1965	789	16,004		8,955		7,804
1966	801	10,689		9,050		7,880

EC and Instantaneous Flow Data. Annual Average Values					Partially missing data	
	Lee's Ferry		Below Parker Dam		Above Imperial dam	
	9380000	9380000	9427520	9427520	9429490	9429490
Year	(mmhos)	(cfs)	(mmhos)	(cfs)	(mmhos)	(cfs)
1967	939	10,442		8,869		7,818
1968	972	12,127		8,884		7,981
1969	923	12,539		8,977		7,849
1970	950	11,242		9,029		7,938
1971	858	12,788		9,597	1,431	8,071
1972	863	12,873		9,555	1,356	8,155
1973	889	12,492		9,128	1,334	7,844
1974	865	12,276		10,082	1,330	8,713
1975	832	12,377		9,754	1,310	8,329
1976	846	12,948		9,508	1,312	8,338
1977	891	10,157		9,292	1,310	7,978
1978	940	12,440		9,299	1,322	7,870
1979	912	11,201		9,518	1,304	8,092
1980	842	15,605		13,169	1,234	11,538
1981	843	10,840		12,057	1,295	10,544
1982	913	12,454		8,781	1,280	7,504
1983	821	26,497	1,052	19,140	1,191	17,359
1984	752	28,065	994	29,025	1,087	27,403
1985	663	23,326	915	24,452	982	22,542
1986	679	25,819	858	22,118	926	20,321
1987	710	15,905	873	15,587	999	14,315
1988	817	10,811	947	10,718	1,072	9,533
1989	757	11,074	899	9,697	1,140	8,311
1990	861	10,914	949	9,661	1,168	8,287
1991	921	11,581	1,004	9,500	1,243	7,924
1992	921	11,025	1,043	8,290	1,223	7,129
1993	897	11,391	990	7,552	1,218	6,554
1994	797	11,095	1,099	9,557	1,218	8,169
1995	807	14,096	1,086	12,162	1,218	7,692
1996	732	15,235	1,047	12,260	1,270	8,354
1997	719	21,099	981	14,136	1,147	10,318
1998	675	18,071		16,133	1,056	12,930
1999	724				1,086	
Average	**983**	**15,264**	**982**	**12,512**	**1,209**	**11,223**

Note: Data sources for the above data are from NCDC EarthInfo CD.
USGS Water Resource Data Books, USGS Data for Imperial Dam,
1942-1979 was not measured but calculated and published in the Water
Resource Data book for the corresponding water year. This data was faxed to
NRCE from the USGS office in Tuscon Az. From Chris Smith ph: 520-670-6671, fx: 520-670-5592
Received 3-14-00

Attachment 28

Water Study Team. (1998). "Imperial Irrigation District Water Use Assessment for the Years 1987-1996."

IMPERIAL IRRIGATION DISTRICT
WATER USE ASSESSMENT
FOR THE YEARS 1987-1996

March 1998

prepared for

Imperial Irrigation District

by the

Water Study Team (WST)

Executive Summary

Performance Parameter Estimates for the IID Study Area

Consumption

Irrigation Consumptive Use Coefficient (ICUC). On average, over the 1987-1996 period, about **66%** of the irrigation water entering the IID study area from the All American Canal at the East Highline Canal was consumed within that area. This value is known (95% confidence level) to within approximately ± 2.8%: [63.2% ≤ ICUC ≤ 68.8%]. The consumed portion decreased approximately one-half of one percent per year over the study period, and this trend is statistically significant. Thus a smaller portion of the irrigation water supply is consumed today than was a decade ago (approximately a 4% reduction in consumed portion over the decade). Some of the reduction in ICUC was necessary to offset increased salinity of Colorado River water occurring during the past decade.

Efficiency

District Irrigation Efficiency ($IE_{District}$). On average, over the 1987-1996 period, the district irrigation efficiency within IID averaged **71%**. This value is known (95% confidence level) to within approximately ± 5.5%: [65.5% ≤ $IE_{District}$ ≤ 76.5%]. Variations in district irrigation efficiency over the study period are statistically insignificant.

District Distribution Efficiency ($DE_{District}$). On average, over the 1987-1996 period, the district distribution efficiency for IID averaged **92%**. This value is known (95%) confidence level) to within approximately ±0.9% [91.1% ≤ $DE_{District}$ ≤ 92.9%]. This resulted from a small decrease in distribution system losses combined with an increase in water delivered. This reduction in **percentage** of distribution system losses was statistically significant, although the magnitude of the change is small.

Aggregate Farm Irrigation Efficiency (IE_{Farm}). On average, over the 1987-1996 period, the aggregate farm irrigation efficiency within IID averaged **76%**. This value is known (95%

Attachment 29

Weir, W. W. and Storie, R. E. (1947). "Soils of a Portion of Palo Verde Valley between the Levee and the River."

UNIVERSITY OF CALIFORNIA · COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY 4, CALIFORNIA

SOILS OF A PORTION OF PALO VERDE VALLEY

(Between the Levee and the River)

RIVERSIDE COUNTY, CALIFORNIA

By
WALTER W. WEIR and R. EARL STORIE

DIVISION OF SOILS

BERKELEY CALIFORNIA
AUGUST 1947

4751

SOILS OF A PORTION OF PALO VERDE VALLEY

(Between the Levee and the River)

WALTER W. WEIR[1] and R. EARL STORIE[2]

LOCATION AND DESCRIPTION OF THE AREA

Introduction

Palo Verde Valley is located in southeastern Riverside County, California, occupying one of the flood plains of the Colorado River. Although portions of the valley have been in cultivation since the late seventies, the completion of the present levee system in 1922--which has since protected the valley from periodic overflow--and the development of adequate irrigation have stimulated agricultural development to a point where the major portion of the 40,000 acres between the levee and the mesa is in cultivation.

That portion of the valley lying between the levee and the river was described in the report on the Soils of Palo Verde Area[3] as

"Alluvial soils undifferentiated....This area is flooded with every period of high water and the soils were not mapped in detail because of their inaccessibility."

The control of floods on the Colorado River, through the construction of the Hoover Dam and the storing of floodwaters in Mead Lake, has materially changed conditions. That portion of Palo Verde Valley between the levee and the river is no longer subject to overflow.

Within the last few years, considerable portions of this area have been cleared of brush and trees and put into cultivation. The irrigation system is being extended to cover these lands as rapidly as they are being developed.

Late in 1946 the University of California was requested by the Palo Verde Irrigation District to extend the detailed soil survey to cover the lands between the levee and the river.

Physiography of the Area

The area covered by this survey lies in a long narrow strip, from 1 to 3 miles wide, between the Palo Verde levee and the Colorado River. It extends from the intake of the Palo Verde Irrigation District's canal to the Imperial County line, a distance of approximately 21 miles. The area lies only a few feet above the normal water surface in the river, and has a slope from north to south approximating that of the river, which is about 1½ feet per mile. As a result of the construction of storage and diversion dams both above and below the valley, the river channel has not yet become stabilized. At the present time it tends to deepen above the Eherenberg Bridge (U. S. Highway 60), and to deposit the eroded material below the county line.

Both before and since the construction of the levee, the river has frequently changed its course. At times of flood it has cut new channels throughout the area. For a time, these new channels may have become the main channel or they may have been completely refilled by receding or subsequent floods. Thus, the area is a labyrinth of old river and overflow channels now filled with sediment to form a relatively smooth flat flood plain.

Vegetation

Prior to its recent development, this area was covered with a dense growth of cottonwood and willow or mesquite thickets, with an undergrowth of vines and arrow weed. This heavy growth greatly retarded the movement of silt-laden flood waters. As a result, the soils are composed of higher stratified sediments, the texture depending upon the velocity of the flood flow at the particular time of deposition.

DESCRIPTION OF THE SOILS

With only very minor exception, the soils in this area are textural variations of the Gila series. The coarse-to-medium-textured types of the Gila series are light brown to faintly pinkish brown, and the heavy-textured (fine-grained) types are chocolate brown. These soils are slightly calcareous throughout their profiles, and frequently are highly stratified. There is no evidence of aging or downward migration of clay or lime. The logs of borings in this area, found elsewhere in this report, show the stratifications which may occur. Soils of the Gila series are derived from mixed rock alluvium brought into the area by the Colorado River. Although there are some small areas of clay, the medium-textured types predominate. Table 1 gives the areas of each type found in this survey.

These soils are mellow, friable, and easily tilled, although the fine-grained types become very sticky when wet. They produce good to excellent crops of alfalfa, beets, carrots, melons, and other vegetables. Commercial fertilizers are commonly used for vegetables.

Along the Riverside-Imperial County line in sections 34, 35, and 36, and also in section 13, all in

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[1]Drainage Engineer in the Experiment Station.

[2]Soil Technologist in the Experiment Station.

[3]Kocher, A. E., and F. O. Youngs. Soil Survey of Palo Verde Area, California. U. S. Department of Agriculture, Bur. Soils. 1922.